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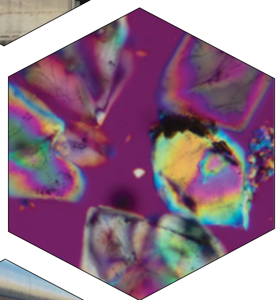

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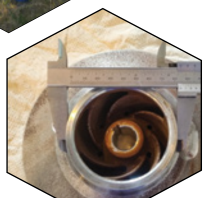

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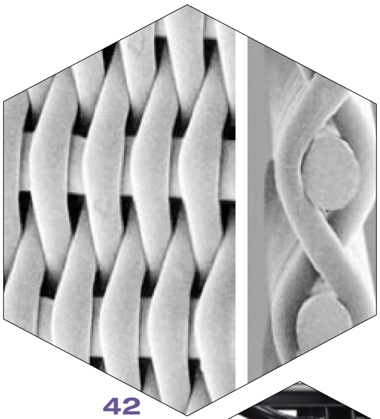

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Cover image: The cover image shows a microscopic view of sodium borate crystals

Cover design: Tara Bekman

CHEMICAL ENGINEERING
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Editor's Page

A vision for chemical engineering

Chemical engineering is a discipline with far-reaching and diverse applications. The list of industries that employ its professionals is extensive: petroleum refining, pharmaceuticals, biomedical, basic and specialty chemicals, mining, agriculture, energy and food-and-beverage, to name a few.

While the basic principles of chemical engineering remain steadfast, rapid advances in technology and the evolving needs of society create new directions and areas of focus for chemical engineers. Recently, leaders from the chemical engineering community concluded a three-year study to outline a vision for the direction of the profession for the next 30 years. This culminated in the report " *New Directions for Chemical Engineering*" by the National Academies of Sciences, Engineering and Medicine (Washington, D.C.; www.nationalacademies.org). The chair of the committee that wrote the report, Eric Kaler, president of Case Western Reserve University, said: "Chemical engineering is often at the heart of solutions to many of the problems we face, but for our field to stay in a position of global leadership and continue our pace of innovation, we need to reaffirm strong investment in this field."

Opportunities for chemical engineering

A brief summary from the over 300-page report on areas where chemical engineers can have the most impact in the coming years follows:

Decarbonization. Chemical engineers are making important contributions to address climate-change-driven efforts to lower carbon emissions through technologies that support low-carbon energy sources, energy efficiency, carbon capture and storage, "green" chemistry, energy storage to support electrification and more. The report recommends that federal research funding be directed to further develop technologies that enable lower-carbon energy sources, cost-effective carbon capture and storage, as well as to develop new technologies that use little or no carbon.

Water, food and air quality. The report suggests that chemical engineers can bring both a "molecular- and systems-level" approach to addressing global needs around water, food and air quality. Collaboration with other disciplines, such as with civil engineers for water use and purification, and with atmospheric scientists for air quality, will be particularly valuable. Chemical engineers can help address the changing needs in the world's food sources through collaboration on advanced agricultural practices, and with researchers who are developing new food sources in the laboratory.

Targeted and accessible medicine. Rapid advances are being made in biology and biochemistry to treat human illness. Chemical engineers can contribute to reactor design and scale-up, separations techniques and non-invasive drug delivery methods. Quantitative engineering skills can also be applied to immunology, such as cancer immunotherapies and vaccine design.

Circular economy. Chemical engineers are working toward sustainability by advancing renewable feedstocks, reducing waste and developing advanced recycling technologies.

Materials. Chemical engineers play a critical role in developing novel materials, such as polymers, biomaterials and electronic materials.

For all of these areas, cross-disciplinary collaboration as well as international cooperation are key to making the highest impact in meeting the evolving needs of the world's population. ■

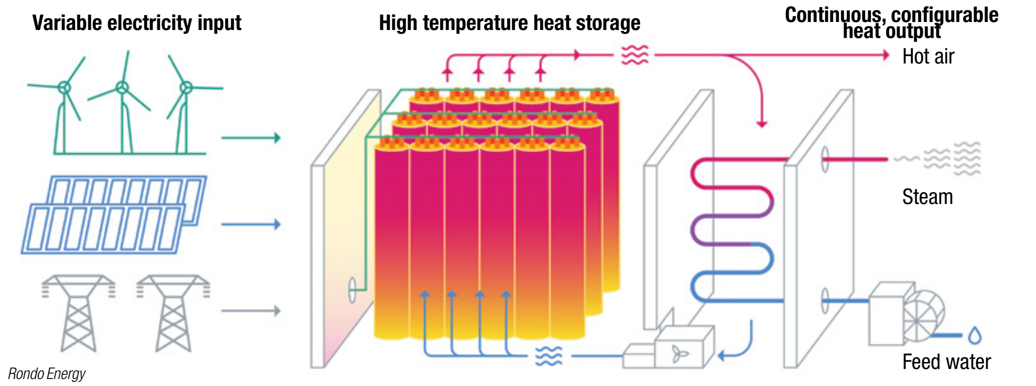
Dorothy Lozowski, Editorial Director

This heat battery is a decarbonized, 'drop-in' replacement for industrial boilers

As the cost of renewable energy decreases, many organizations are looking to electrify their operations to reduce carbon emissions. One promising area for decarbonization is industrial heating, which accounts for a large fraction of global emissions. However, heating networks in plants can be very complex, making modifications to existing configurations extremely costly.

Now, a new "heat battery" developed by Rondo Energy, Inc. (Oakland, Calif.; www.rondo.energy) aims to provide affordable, decarbonized process heat in a drop-in module that can be easily integrated into an existing boiler network, either to replace aging boilers or to complement those still in operation. "We found a way to use well-proven materials in a new combination to build a heat battery that uses renewable electricity to deliver high-temperature heat by circulating air through a solid material to deliver hot air or high-pressure steam at any condition," explains John O'Donnell, CEO of Rondo Energy. To meet the safety requirements of industrial plants, Rondo's technology does not depend on combustion or phase change, and with its low-cost solid heating media, there is no possibility of gas or liquid being released. "The units are safe and compact, and can tie into existing facilities the same way that existing gas- or coal-fired boilers do today," adds O'Donnell. Furthermore, Rondo's system can achieve very high temperatures (up to 1,000°C), whereas energy-storage systems that employ liquid salts may only reach 570°C, which limits their use for industrial applications.

The company expects to announce its first commercial installations later this year and was recently awarded $22 million in Series A funding. "We've made the transition from the laboratory to prototypes to first field installations. These units are now industrial scale — the standard unit delivers 20 MW of steam, which is like a boiler that's burning 85 million Btu/h," says O'Donnell. Furthermore, because the units are equipped with both conventional and dynamic outer insulation layers, heat losses are minimized, resulting in a 98% heat-delivery efficiency.



Rondo Energy

Quantum-inspired computing technology drastically accelerates materials design

Semiconductor materials contain numerous ingredients in various mixing ratios, and high-performance materials are obtained by optimizing the formulation. However, more than 1,050 theoretical combinations of ingredients and mixing ratios need to be analyzed, so it would take more than dozens of years to explore all possible combinations of these ingredients and their mixing ratios with conventional artificial intelligence (AI) methods, according to Showa Denko K.K. (Tokyo, Japan; www.sdk.co.jp).

To reduce the time required for the exploration, the company used high-performance computing technology, Digital Annealer, a domain-specific computer architecture developed by Fujitsu Ltd. (Kawasaki, Japan: www.fujitsu.com) that is inspired by quantum technology (but not directly using quantum effects). Showa Denko developed an AI model for predicting the properties of semiconductor materials. To make the AI model computable on Digital Annealer, Showa Denko expressed the AI model as an Ising model, a statistical mechanical method. By simulating the Ising model on Digital Annealer, the company says it has reduced the exploration time to dozens of seconds, about 72,000 times faster than the time required by conventional AI methods. The optimal formulation designed with the Ising model is expected to obtain semiconductor materials with 30% higher performance than the formulation designed with conventional AI methods, the company says.

Edited by:
Gerald Ondrey

2D POLYMER

Chemical engineers at the Massachusetts Institute of Technology (MIT; Cambridge; www.mit.edu) have synthesized two-dimensional sheets of polyaramide. The achievement, described in a February issue of *Nature*, is said to be the first time a polymer has been grown in 2D, creating a material with unusual properties: films of the material have a 2D elastic modulus of 12.7 GPa (4–6 times greater than that of bullet-proof glass) and a 2D yield strength of 488 MPa (twice that of steel). Combined with a density that is one-sixth that of steel, these properties could make the material find applications as lightweight, durable coatings for mobile devices and cars, or as building materials for bridges and buildings.

The new material, dubbed 2DPA-1, is made by the homogenous 2D irreversible polycondensation of melamine — a spontaneous self-assembly process. The synthesized material can then be spin-coated into thin films. These films are not only strong, but also impermeable to gases, which would make them useful as barrier coatings for metal structures.

Further experiments are underway to learn more about the formation mechanism of 2DPA-1, as well as changing the molecular makeup to create other types of materials.

Two patents have already been filed on the production process.

BIO-HMDA

A partnership between Genomatica (San Diego, Calif.; www.genomatica.com) and Covestro AG (Leverkusen, Germany;

(Continues on p. 6)

www.covestro.com) has produced the first industrially significant volumes of a plant-based version of hexamethylenediamine (HMDA).

HMDA, traditionally derived from petroleum, is a chemical intermediate widely used in the manufacture of Nylon, as well as in coatings and adhesives. Production of ton quantities of bio-based HMDA from the fermentation of sugar allows those products to be produced more sustainably.

Highly efficient engineered bacteria metabolize sugar and produce, in one step, an aqueous solution of HMDA. This "broth" is worked up in a dedicated process to produce HMDA that is suitable for polyurethane and nylon 6,6 applications.

Genomatica is developing the complete, integrated process to make HMDA from renewable feedstocks, along with the steps needed to build and operate a production plant, while Covestro is contributing its expertise in separating and purifying HMDA and testing in polyurethane applications.

Covestro has secured an option to license Genomatica's integrated GENO HMD process technology for commercial production.

PSILOCYBIN

Vocan Biotechnologies Inc. (Victoria, B.C., Canada; www.vocanbiotech.com) has optimized its recombinant production system, successfully testing its proof of concept for the biosynthesis of psilocybin suitable for use in future scale-up. A patent application has been filed. Psilocybin is a psychedelic compound that is showing enormous promise in treating addiction and depression.

Scientists at Vocan have constructed optimized DNA sequences that can produce enzymes replicating the biosynthetic pathway used by *Psilocybe* mushrooms. Vocan's biosynthetic process retains the stereochemistry of the natural psilocybin molecules found

(Continues on p. 8)

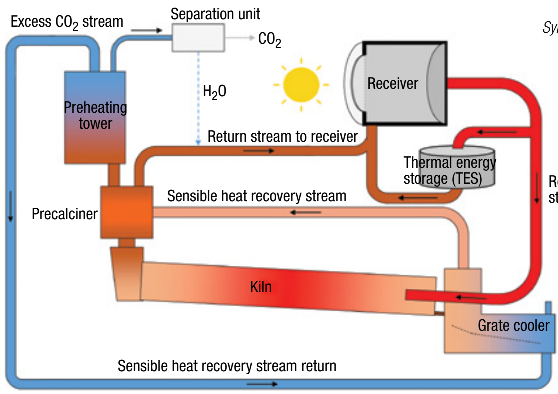
Solar clinker produced for the first time

Last month, Cemex, S.A.B. de C.V. (Cemex; Monterrey, Mexico; www.cemex.com) and Synhelion SA (Lugano, Switzerland; www.synhelion.com) successfully connected the clinker production process with the Synhelion solar receiver to produce solar clinker. The milestone is a first step towards fully solar-driven cement plants.

Clinker — a solid material used for making Portland cement — is produced by fusing together limestone, clay and other materials in a rotary kiln at temperatures nearing 1,500°C. Because fossil fuels are typically used to heat the kiln, they are responsible for approximately 40% of direct CO_2 emissions of the process. Replacing fossil fuels entirely with solar-thermal energy is a gamechanger in the industry's efforts to achieve carbon neutrality by 2050.

The Synhelion and Cemex R&D teams set up a pilot batch-production unit to produce clinker from concentrated solar radiation by connecting the clinker production process with the Synhelion solar receiver. The pilot was installed at the Very High Concentration Solar Tower of IMDEA Energy, located near Madrid, Spain. Synhelion's solar receiver consists of a cavity filled with a greenhouse gas (GHG; typically water vapor or mixtures of H_2O and CO_2) flowing from the aperture towards the back of the cavity. Solar radiation coming from the 1,000-m^2 field of 169 mirrors enters the cavity through a transparent window and is absorbed by the black surface of the cavity walls. The energy is then thermalized and reradiated back into the cavity to heat up the GHGs, which is then used as a heat-transfer fluid to deliver process heat for clinker production. With this design, record-breaking temperatures above 1,500°C are achieved.

The pilot, which produced a few kilograms per batch, is the first successful calcination and, more importantly, the first successful clinkerization ever achieved using only solar energy. The next step this year will target continuous production (during daytime), which will be followed by a dedicated pilot facility with a ten-fold increase in capacity. A first small-scale industrial plant is envisioned by 2026 and a full-scale industrial plant (150 MW_{th} solar input power, 900 ton/d production capacity) by 2028. The process (diagram) will use Synhelion's thermal-energy storage, which will enable continuous operation — even at night.



Synhelion/Cemex

A new catalyst for the oxidative dehydration of propane with CO_2

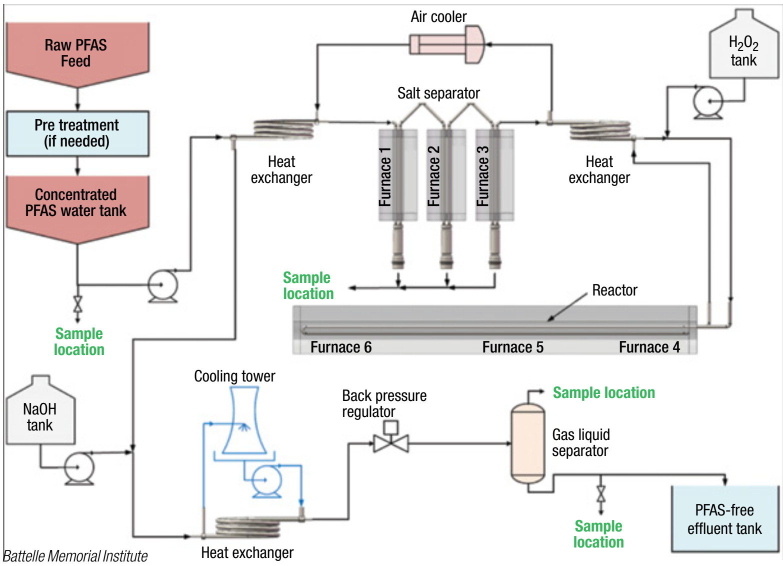
Converting propane to propylene by oxidative dehydrogenation with CO_2 is an alternative route to conventional propane dehydrogenation, but existing catalysts for this conversion are not very efficient. Now, in a study described in a recent issue of *Nature Catalysis*, researchers at the Institute for Catalysis, Hokkaido University (Sapporo, Japan; www.cat.hokudai.ac.jp) have developed a highly efficient catalyst — a Pt-Co-In ternary nanoalloy on a ceria (CeO_2) support — that exhibits a very high catalytic activity, C_3H_6 selectivity, stability and CO_2-utilization efficiency.

Each of the three metals were chosen for their specific properties: Pt as the main active metal due to its ability to break C–H bonds; Co for accelerating CO_2 capture and activation; and In to enhance the selectivity.

The researchers tested the catalyst's activity at 550°C and compared the results with existing catalysts. They also performed a mechanistic study to understand the functions of the different components and found the catalyst links the propylene-forming reaction to the deoxygenation of CO_2, and ensures the catalytic activity is specific to propane; water and carbon oxides are formed as byproducts. They also found that the catalyst increased the reaction rate approximately five-fold compared to the typical values reported from other systems. The reaction produced a higher ratio of propylene and utilized more CO_2 at 550°C compared to previous catalysts. The stability of the catalyst is greatly enhanced by combining the strong CO_2 activation ability of the alloy with the oxygen-releasing ability of the ceria support, which facilitates Mars–van Krevelen-type coke combustion.

PFAS destruction using supercritical water

The presence of per- and polyfluoroalkyl substances (PFAS) in wastewater and groundwater has garnered increased attention as a health and environmental issue because of their recalcitrance and bioaccumulation. To complement existing PFAS separation technologies, the Battelle Memorial Institute (Columbus, Ohio; www.battelle.org) has developed a technology, known as the PFAS Annihilator, for destroying both short- and long-chain PFAS compounds using supercritical water oxidation (SCWO). This month, the first on-site deployment of the technology has begun at a wastewater treatment plant.



Battelle Memorial Institute

Above its critical point (>374°C and >221 bars), water has both liquid and gas properties. The Battelle process uses water around these temperatures and pressures to mineralize a wide range of PFAS species. This new SCWO technology is related to similar processes used previously to destroy polychlorinated biphenyls (PCBs), but now has been optimized to destroy PFAS molecules.

In the process (diagram), an oxidant is introduced into the supercritical water reactor, and a base (NaOH) is added to neutralize the hydrofluoric acid formed by the reactions. The PFAS Annihilator has demonstrated the ability to destroy 99.99% of total PFAS in various aqueous feeds, Battelle says, leaving inorganic salts, such as NaF and Na_2SO_4, as inert end-products.

"Battelle's SCWO PFAS-destruction technology can be used alone or in combination with another process that can concentrate the PFAS before it is destroyed," explains Dan Longbrake, director of commercial business at Battelle. "To date, our focus for PFAS Annihilator has been on aqueous wastes, such as PFAS-containing wastewater or landfill leachate, but Battelle is also developing SCWO for destruction of PFAS in solid materials, such as contaminated soil," notes Longbrake. The technology will also be deployed to reduce or eliminate stockpiles of firefighting foams, which contain high levels of PFAS.

The PFAS Annihilator is available as a mobile unit that can be transported on a trailer for episodic and demonstration uses. Battelle is also constructing a larger mobile unit.

in hallucinogenic mushrooms, which are known to have a more positive effect than the chemically synthetized counterpart.

CARBON FIBERS

The Competence Center Biopolymer Materials of the German Institutes of Textile and Fiber Research (DITF) Denkendorf (Germany; www.ditf.de) has developed a sustainable process for the production of carbon fibers. The HighPerCellCarbon technology is a patented process, which has been further developed under the leadership of Frank Hermanutz, that enables carbon fibers based on biopolymers to be produced in a sustainable and particularly environmentally friendly process. The process involves the wet spinning of cellulose fibers using ionic liquids (IL) as direct solvents. The filament spinning-process takes place in a closed system, and the IL solvent is completely recycled. The cellulose fibers produced

(Continues on p. 9)

A sulfur-tolerant catalyst for the deoxygenation of sulfoxides

The transformation of sulfur-containing molecules is an important reaction in organic and pharmaceutical chemistry. However, the sulfur atom strongly coordinates with the active sites of metal catalysts, significantly decreasing the catalytic performance. Sulfur impurities contained in chemical feedstocks also cause catalyst deactivation. Therefore, the development of a new sulfur-tolerant and highly active catalyst is desired.

To meet this need, researchers at Osaka University (Japan; www.osaka-u.ac.jp) have developed a highly active and durable metal-phosphide catalyst for the deoxygenation of sulfoxides into sulfides. As described in a recent issue of the *Journal of the American Chemical Society Au*, the developed catalyst has a high durability against sulfur-poisoning in contrast with the conventional metal catalysts.

The catalyst — precious metal phosphide nanoparticles — is prepared by integrating phosphorus into the metal framework using a technique known as phosphorus-alloying. In doing so, the catalytic performance of the precious metal nanoparticles is said to be greatly improved. In particular, the ruthenium phosphide nanoparticles ($Ru–P/SiO_2$) exhibited a ten-times higher catalytic activity than Ru/SiO_2. In one of the reactions studied, the deoxygenation of diphenylsulfoxide, $(C_6H_5)_2SO$, over Ru-P/SiO_2 (with 50 bars H_2 at 453K) exhibited a turnover number of 12,500 — the highest to date, according to the researchers — and a yield of more than 99% for diphenyl sulfide, $(C_6H_5)_2S$.

According to the researchers, this catalyst shows wide substrate applicability and can deoxygenate structurally complex drug intermediates to produce bioactive sulfides in high yields. Moreover, Ru–P/SiO_2 can promote sulfoxide deoxygenation even in the presence of a lot of sulfur-containing molecules where conventional Ru/SiO_2 is completely deactivated.

in this way are converted directly into carbon fibers by a low-pressure stabilization process, followed by a carbonization process. Petroleum-based raw materials, which are usually used in the industrial production of carbon fibers, are substituted by renewable biopolymers.

E-CRACKING

Coolbrook Oy (Helsinki, Finland; www.coolbrook.fi) and ABB Ltd. (Zurich, Switzerland; www.abb.com) have signed a memorandum of understanding (MoU) to commercialize and accelerate the adoption of Roto Dynamic Reactor (RDR) technology that promises to significantly reduce greenhouse gas emissions from steam cracking of olefins. The agreement will unite the two companies' expertise and create a combined

(Continues on p. 10)

Ultra-rapid production of battery materials using plasma technology

A new ultra-rapid plasma-based process could significantly expand the availability of premium materials for battery applications. Developed by 6K, Inc. (North Andover, Mass.; www.6kinc.com), UniMelt is a single-pass, continuous process that employs a proprietary microwave torch technology to create a ball of plasma at 6,000K, which can be stretched into a large production zone. The base materials for battery cathodes are dissolved in an aqueous solution, which is sprayed into the plasma reactor using a high-speed droplet sprayer, where the water from the solution is immediately evaporated and captured as steam. "Then, over the next 2–3 s, the battery materials travel through the production zone and the particle is synthesized. Depending on the battery chemistry, the particle is either ready for use, or it may need a 1–3-h heat treatment to complete the final product," explains Sam Trinch, 6K's president. This is a vast improvement over current processes, such as coprecipitation, which can take as long as 3 d.

"We can process materials from 10 nm up to hundreds of micrometers, which is a very large span of particle sizes for a single process, while also demonstrating many different chemistries are possible," notes Trinch. Currently, one of industry's most attractive chemistry blends is nickel-manganese-cobalt oxide (NMC), and with the UniMelt process, the stoichiometry of the blend, as well as the final particle size, can be finely tuned by simply controlling the proportions in the aqueous feed, as well as the process gases (such as N_2 or O_2) injected during the reaction. Beyond NMC, UniMelt is also expanding the exploration of additional battery materials, such as lithium titanate (LTO), lithium lanthanum zirconium oxide (LLZO) and various silicon anodes.

The company is operating two 100-ton/yr UniMelt units in Pittsburgh that produce powders for additive manufacturing, and the company is investing $35 million to scale up the process for battery applications at a dedicated facility in Massachusetts. "The new center will have ten manufacturing systems for pilot production. By the end of 2022, we should have roughly 200 to 300 MWh worth of active cathode materials capacity," adds Trinch.

offering of Coolbrook's electrically driven RDR technology and ABB's integrated, pre-engineered energy solutions, initially for use in petrochemical and chemical markets.

Coolbrook's RDR turbomachine will be able to replace a conventional furnace by directly imparting the rotor shaft's mechanical energy to the hydrocarbon fluid. This is achieved by aerodynamic action through a rotating blade flow (for more details, see *Chem. Eng.*, May 2017, p. 9). When powered by electricity from renewable sources, the technology completely eliminates CO_2 emissions in the steam-cracking process.

ABB will deliver automation, electrification and digitalization to optimize operational processes and simplify integration, as well as enhance the energy efficiency of Coolbrook's solution through the integration of ABB's electric motors and variable-speed drives. ❐

Rubber electrolytes could stretch the capabilities of solid-state batteries

A new class of electrolyte aims to bridge the performance gaps between the electrolytes used in conventional lithium-ion batteries and solid-state batteries. The new rubber electrolytes, developed by a team of researchers from Georgia Institute of Technology (Georgia Tech; Atlanta; www.gatech.edu), led by mechanical engineering professor Seung Woo Lee, provide several distinctive benefits for batteries in terms of safety and mechanical stability.

A major drawback of conventional liquid electrolytes is their flammability, which has spurred much research into solid-state batteries. However, explains researcher Michael Lee, solid electrolyte materials often require complex manufacturing processes, and the materials may decompose at ambient conditions, potentially releasing toxic chemicals. Furthermore, they exhibit low ionic conductivity at room temperature, meaning that they often require an elevated temperature to operate, which may necessitate thermal management systems in some applications. The new rubber electrolytes are not only flame-retardant, but also can be fabricated using current roll-to-roll manufacturing processes employed in battery manufacturing. "Compared to other electrolytes, rubber electrolytes have a high ionic conductivity at room temperature and excellent mechanical toughness. Thus, batteries with rubber electrolytes can be more safely operated at room temperature," explains Lee.

The rubber electrolyte is composed of lithium salt, a cross-linked elastomer matrix (poly butyl acrylate) and a plastic crystal (succinonitrile). The materials are synthesized into a 3D-structured rubber electrolyte matrix. Upon polymerization, the plastic crystal component creates 3D interconnected pathways for lithium ion transport, enabling high ionic conductivity at room temperature, while the elastomer component provides mechanical stability. The team at Georgia Tech has fabricated a 4-in. × 7-in. free-standing rubber electrolyte, and is working on scaling up rubber-electrolyte assembly for pouch-type batteries. The team has received funding from major battery manufacturer SK Innovation Co. (Seoul, South Korea; eng.skinnovation.com) to further develop next-generation battery materials. ■

Business News

Plant Watch

Lummus and Synthos double planned capacity of bio-butadiene plant

February 10, 2022 — Following a successful feasibility study last year, Lummus Technology (Houston; www.lummustechnology.com) and Synthos S.A. (Oswiecim, Poland; www.synthosgroup.com) announced that their new bio-butadiene technology is ready for implementation, and the companies have agreed to move into the next phase of the project. Synthos has committed to building a plant with a capacity of 40,000 metric tons per year (m.t./yr) of bio-butadiene — twice as much as the companies had originally planned.

Hexion to expand capacity for fire-protection products at Montana plant

February 9, 2022 — Hexion Holdings Corp. (Columbus, Ohio; www.hexion.com) is strengthening its manufacturing footprint for the ArmorBuilt fire-protection product through an expansion of its site in Missoula, Mont. Hexion previously announced two ArmorBuilt capacity expansions at its Portland, Oregon manufacturing site in 2021. The Missoula site expansion will significantly increase ArmorBuilt capacity when it comes online in late 2022.

Linde to build hydrogen plant for BASF in France

February 9, 2022 — Linde plc (Guildford, U.K.; www.linde.com) will design, build, own and operate a new hydrogen production facility at Chalampé, France, effectively doubling Linde's current capacity in the Chalampé chemical park where it already has one plant. This second plant will supply BASF SE's (Ludwigshafen, Germany; www.basf.com) new hexamethylenediamine facility, which is slated for startup in 2024.

Air Liquide to build world-scale biomethane plant in Illinois

February 4, 2022 — Air Liquide S.A. (Paris; www.airliquide.com) plans to construct its largest biomethane production unit in the world in Rockford, Ill. The site will be designed to produce 380 GWh/yr of biomethane from solid-waste-derived biogas. It will be operational by the end of 2023. An additional biomethane production unit from another landfill is also being built in Delavan, Wisconsin, and will be operational in the second quarter of 2022.

Eastman completes significant expansion of tertiary amine capacity

February 3, 2022 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) completed a significant expansion of its tertiary amine capacity, at both its Ghent, Belgium, and Pace, Florida, manufacturing sites. The Ghent expansion has led to an increase in capacity, while the Pace expansion has improved production flow, making it the world's largest tertiary amine unit.

Kemira starts up first production line for bio-based polyacrylamide

February 3, 2022 — Kemira Oyj (Helsinki, Finland; www.kemira.com) announced that it has started the first full-scale production of its newly developed polymer based on bio-based feedstock — a biomass-balanced polyacrylamide. These water-soluble polymers can be used in various industries, such as water, energy and papermaking.

Stamicarbon announces startup of Brunei fertilizer plant

February 3, 2022 — Stamicarbon BV (Sittard, the Netherlands; www.stamicarbon.com) announced the successful startup of Brunei Fertilizer Industries' new urea melt plant in Brunei. With a nameplate capacity of 3,900 m.t./d, the plant is the largest to be licensed by Stamicarbon to date.

Nouryon commissions chelates plant in the Netherlands

February 1, 2022 — Nouryon (Amsterdam, the Netherlands; www.nouryon.com) completed a production facility for sustainable chelates, which will double the company's production of methylglycine *N*,*N*-diacetic trisodium salt (MGDA), glutamic acid, *N*,*N*-diacetic tetrasodium salt (GLDA) and other ingredients. The startup of the new site in Herkenbosch, the Netherlands is expected in the second quarter of 2022. The new site will complement the company's existing plants in China and Ohio.

Solvay announces PVDF capacity expansion in France

February 1, 2022 — Solvay S.A. (Brussels, Belgium; www.solvay.com) is expanding its production capacity of polyvinylidene fluoride (PVDF) at its site in Tavaux, France. Building on its previously announced PVDF capacity increase in Changshu, China, this new project will expand Solvay's capacity in Europe to 35,000 m.t./yr, creating the largest PVDF production site in the region. This investment will be completed by December 2023.

BASF to increase production capacities for chloroformates and acid chlorides

January 31, 2022 — BASF plans to modernize the entire infrastructure, including the facilities for the production of chloroformates and acid chlorides, at its Ludwigshafen *Verbund* site. The measures, which are anticipated to be completed by 2025, will increase the company's capacity for these products at the site by around 30%.

LINEUP

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Mergers & Acquisitions

PPG to acquire Milan-based powder coatings business

February 7, 2022 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) entered into an agreement to acquire the powder coatings business of Arsonsisi, an industrial coatings company based in Milan, Italy. As part of the transaction, PPG will acquire Arsonsisi's automated, small- and large-batch-capable powder manufacturing plant in Verbania, Italy.

EuroChem offers to acquire Borealis' nitrogen business

February 3, 2022 — Borealis AG (Vienna, Austria; www.borealisgroup.com) has received a binding offer from Eurochem AG (Zug, Switzerland; www.eurochemgroup.com) for the acquisition of Borealis' nitrogen business, including fertilizer, melamine and technical nitrogen products. The offer places the business on an enterprise value basis at €455 million. The transaction is subject to certain closing conditions and regulatory approvals, with closing expected for the second half of 2022.

Sabic to purchase Clariant's stake in Scientific Design JV

February 2, 2022 — Sabic (Jubail, Saudi Arabia; www.sabic.com) agreed to purchase Clariant AG's (Muttenz, Switzerland; www.clariant.com) 50% stake in the companies' 50-50 joint venture (JV), Scientific Design. Headquartered in New Jersey, Scientific Design is a licensor of high-performance process technologies and a developer of catalysts that are used in over 100 plants across more than 30 countries.

Alpek acquires PET sheet manufacturer Octal

February 2, 2022 — Alpek S.A.B. de C.V. (San Pedro Garza Garcia, Mexico; www.alpek.com) has signed an agreement to acquire Oman-based Octal Holding SAOC, a manufacturer of polyethylene terephthalate (PET), for $620 million. The acquisition adds over 1 million m.t./yr of installed capacity to Alpek's existing footprint, comprising: 400,000 m.t./yr of PET sheet in Salalah Free Zone, Oman; 33,000 m.t./yr of PET sheet recycling in Cincinnati, Ohio; 11,000 m.t./yr of PET thermoform packaging in Riyadh, Saudi Arabia; and 576,000 m.t./yr of PET resin in Salalah Free Zone, Oman.

TotalEnergies and Veolia join forces for biomethane production

February 2, 2022 — TotalEnergies SE (www.totalenergies) and Veolia (both Paris; www.veolia.com) signed an agreement to produce biomethane from Veolia waste- and water-treatment facilities operating in more than 15 countries. The partners will jointly develop and co-invest in a portfolio of projects, with the ambition to produce up to 1.5 TWh/yr of biomethane by 2025.

ExxonMobil to combine its chemicals and refining companies

February 2, 2022 — ExxonMobil Corp. (Houston; www.exxonmobil.com) is combining its chemical and downstream companies into a new business line, ExxonMobil Product Solutions. Effective April 1, the company will be organized along three business lines: Upstream, Product Solutions and Low Carbon Solutions. ■

Mary Page Bailey

Corrosion Under Insulation Gets Attention at CPI sites

Corrosion under insulation (CUI) remains a persistent challenge at chemical process industries facilities, but the issue is receiving renewed attention amid a host of technologies, materials and methodologies for detection and prevention of CUI

Corrosion of process equipment, piping and structural elements is an ongoing problem at chemical process industries (CPI) facilities because of its potential to contribute to catastrophic failures, safety concerns and increased cost and effort for maintenance. The corrosion subcategory known as corrosion under insulation (CUI) is a particularly difficult challenge for plants to address as industrial sites continue to seek efficiency gains and avoid heat loss by insulating process equipment. By its nature, CUI is hidden from view, and it can progress quickly under certain circumstances. The renewed attention on CUI has been highlighted by new coating technologies and detection methods, aimed specifically at the problem of CUI.

FIGURE 1. Corrosion under insulation (CUI) is a phenomenon that can be particularly aggressive when the presence of moisture is combined with contaminants at a steel surface, and so it can progress rapidly between asset inspection intervals

IN BRIEF

Corrosion knowledge base

Professor Homero Castenada-Lopez, the director of the National Corrosion and Materials Reliability Center at Texas A&M University (College Station, Tex.; www.tamu.edu), works with companies on improving corrosion performance for their assets, including testing different materials in various environments and identifying which control actions would be most effective at increasing safety and reliability. "The ultimate goal is to avoid all catastrophic incidents," Castenada-Lopez says, "and when you have aging infrastructure and assets, it requires that we be proactive, rather than reactive, at preventing corrosion." In part, that requires closing the current knowledge gaps and developing a deeper and more widespread understanding of corrosion," he notes.

"While most people on industrial sites have a general awareness about corrosion's potential impact, there remains a great need for improving the knowledge base on corrosion, not only for chemical engineers, but also for mechanical engineers and others," says Castenada-Lopez.

Castenada-Lopez says the issue of corrosion under insulation (CUI) has been garnering significant focus recently, because it remains a large problem for which there have not generally been efficient solutions. "It's a stubborn problem that is going to be worse in the future," he says.

Steven Reinstadtler, infrastructure market manager at Covestro LLC (Pittsburgh, Penn.; www.covestro.com) and committee chair with the Association for Materials Protection and Performance (AMMP; Houston; www.ampp.org), has also seen a renewed focus on CUI. "In the past, any solutions for CUI were extremely limited and individual components-based," he says, "Now, while CUI remains a significant problem, some solutions are available that do address the issue, although they tend to be complex and involve multiple components working in concert, and so therefore, can be somewhat expensive," Reinstadtler comments.

Isolated and aggressive

CUI occurs when moisture mixes with contaminants in a "corrosion zone" between the interior of the insulation and the coating on the surface of the asset. "Moisture

ENVIRONMENTAL PERFORMANCE OF ANTICORROSION COATINGS

Aside from CUI prevention, another prominent trend in industrial coatings is the pursuit of enhanced environmental performance of anticorrosion coatings, in part by lowering the level of volatile organic compounds (VOCs) in the coatings and also by using bio-based materials.

Covestro's Reinstadtler explains: "over the past few years, substantial VOC reductions have been achieved for coatings that are designed for more aesthetic purposes, and that don't place such a premium on durability, such as architectural and decorative paints. But the push for lower-VOC coatings had not extended to the same degree to industrial protective coatings until now, because the need for performance and durability was so high."

Now, regulators at the state and federal levels are taking a tougher look at lowering VOC requirements for industrial coatings, and possibly de-listing solvents that are currently exempt from VOC limits. As a result, coatings manufacturers are investing a lot of development effort toward making formulations that will address anticipated lowering of VOC levels and elimination of some exempt solvents for industrial coatings. VOC and solvent discussions relative to industrial coatings are happening now with the California Air Resources Board and the South Coast Air Quality Management District, Reinstadtler says, and will extend to other regulatory bodies in the future.

An example is the recent development by Covestro of a new technology using polyaspartic resins and unique aliphatic hardeners for anti-corrosion topcoats. Designed to "future-proof" the product line by meeting anticipated future regulations on lower VOCs and the delisting of exempt solvents, the new coating contains less than 100 g/L VOCs and does not use any exempt solvents, Reinstadtler says, explaining that the technology is a two-component system using Desmophen NH polyaspartic resins reacted with Desmodur aliphatic hardeners to create a polyaspartic coating. The system is scheduled be discussed in full detail at the AMMP conference this month.

The effort to reduce VOCs without compromising on anticorrosion performance has also been taken up by BASF SE (Ludwigshafen, Germany; www.basf.de). Although solvent-borne systems are still prominent in many direct-to-metal (DTM) coating applications, water-based binders are increasing in popularity because of the lower VOC profile offered by waterborne systems, as well as their ability to combine the physical characteristics of a top-coat system and a primer in one layer, reducing time and cost of application. BASF says "coatings formulators have struggled to obtain the same levels of performance with waterborne DTM coatings," so the company developed Acronal Pro 770, "a new acrylic high-performance binder with improved corrosion protection compared to other one-component binders at the same DFT."

The "greening" of corrosion coatings extends to efforts to increase the bio-based content in coatings formulations as an alternative to petroleum-derived components. In that area, Covestro has developed Desmodur eco N, an aliphatic hardener containing 71% bio-based content. "It's the first new aliphatic hardener in 30 years," says Covestro's Reinstadtler. While it was originally designed for the automotive sector, Desmodur eco N is now being evaluated for other sectors, he says.

The Desmodur eco N hardener is used with typical polyurethane resins. "It's close to being a drop-in replacement for a traditional aliphatic hardener — there are similar properties in the final coating," Reinstadtler says. Besides polyurethane clearcoats for the automotive sector, Covestro is testing the bio-based aliphatic hardener for other low-VOC applications, such as corrosion-resistant, light-stable topcoats for steel infrastructure, as well as roof and industrial concrete floor coatings. ❑

mixed with contaminants frequently enters this area through small gaps in the insulation system's cladding," explains Thomas Crenshaw, the downstream facilities subject matter expert at Sherwin-Williams' (Cleveland, Ohio; www.sherwin-williams.com) protective and marine division. "The moisture and contaminants become trapped in the corrosion zone and face thermal cycling, eventually causing CUI," he says.

CUI is a particularly vexing problem for plant personnel for several reasons, according to Crenshaw. When CUI occurs, it is typically in isolated locations and especially aggressive, so it may not be identified between inspection intervals, he explains (Figure 1). Also, engineers often fail to take into account that process equipment will experience upset conditions, which may include temperature spikes that exceed the applied coating's exposure limits, causing the material to crack or blister. Planning ahead and specifying more robust materials to accommodate potential spikes is helpful, Crenshaw says.

Heat-cycling and large temperature swings are important factors in CUI. The temperature swings don't cause corrosion by themselves, but they cause coatings to crack and age rapidly, allowing corrosion to develop, Crenshaw says. "Shutdowns and turnarounds allow the process equipment to be at risk for significant corrosion, as condensation is likely to occur at lower temperatures, and that moisture will later boil on the steel surface when temperatures rise" (Figure 2). Steam-out cleaning and processes that normally experience temperature swings are other examples of situations that can lead to conditions that promote CUI.

CUI-resistant coatings

Over the last decade, Sherwin-Williams has made numerous improvements to a silicone-based, inert multipolymeric matrix (IMM) coating aimed at preventing CUI on process equipment due to its resistance to thermal shock and cycling. The company's Heat Flex 1200 coating is currently in its third generation, and most recently, the company added a curing additive to the formulation for improved mechanical protection. Sherwin-Williams says the Heat Flex 1200 IMM product met the most stringent pass criteria for oil-and-gas atmospheric systems and resisting stress corrosion cracking in accelerated CUI simulation testing with no cracking, flaking or rusting occurring before 265°C (509°F).

Another recent advancement in the company's silicone-based anticorrosion coating line is the addition of micaceous iron oxide (MIO) flakes to the Heat Flex 1200 coating.

"The MIO flakes form a layered barrier that blocks moisture, oxygen and other elements from penetrating the coating and also deflects ultraviolet (UV) rays to minimize coating

FIGURE 2. Heat-cycling is an important factor in causing CUI, because it can lead to condensation, which introduces moisture into the corrosion zone at the component surface

degradation from sunlight," explains Crenshaw. "Considering the plate-like structure of the MIO pigment, it creates a very difficult path for water to permeate the coating and reach the substrate."

Sherwin-Williams has also recently completed testing on the inclusion of MIO flakes in other coatings, some of which have shown promise for CUI resistance. Among them is a high-temperature epoxy phenolic — a two-component, amine-cured lining with excellent resistance to chemicals and hydrocarbons that showed promise in the laboratory as a CUI mitigator, achieving a maximum temperature rating of 205°C, the company says. Also, a MIO-filled high-temperature epoxy based on flake-filled advanced alkylated amide technology resisted CUI in temperatures ranging from cryogenic levels to 200°C (392°F).

"While MIO-enhanced coatings haven't been historically viewed as a solution for CUI in various operations, successful laboratory tests for the coatings noted above give the industry hope for better CUI mitigation tools when assets require external insulation systems," Crenshaw says.

Another CUI coating option focused on resisting temperature cycling comes from PPG Industries Inc. (Pittsburgh, Pa.; www.ppg.com). Last year, PPG launched its HI-TEMP 1027HD coating into the North American market. The coating is described as a next-generation, ambient-cure coating engineered for challenging CUI conditions. PPG says the product is "a high-build coating that offers dry-film thickness of 10 to 12 mils in a one-coat application." The HI-TEMP 1027HD coating provides "excellent protection" against corrosion on pipes, vessels and construction parts when plants are in operation, the company says. The highly durable coating is formulated to withstand severe temperature cycles ranging from –320°F (–196°C) to 1,000°F (540°C), and resists dry exposure with intermittent temperature peaks of up to 1,200°F (650°C). "Because of its hardness and resistance to thermal shock and cycling, PPG HI-TEMP 1027HD coating more effectively protects these critical assets against corrosion. This can extend maintenance intervals and minimize the risk of unexpected shutdowns," the company says.

HI-TEMP 1027HD coating also protects coated pipes, parts and assemblies in changing ambient temperature conditions. This is critical during shipping, because these components are commonly transported between continents and exposed to months of rain, snow, ultraviolet (UV) light and other environmental hazards, PPG notes.

Coatings as insulation

A different approach addressing CUI is to eliminate the "corrosion zone" between an asset's coating and the interior of traditional insulations, such as mineral wool. A new coating now undergoing trials at Sherwin-Williams has the potential to eliminate CUI altogether in many applications by acting as its own insulation, thus alleviating the need for traditional insulation. The coating creates a monolithic barrier that bonds to the surface of the asset, leaving no gaps or corrosion zone for moisture to get close to the substrate.

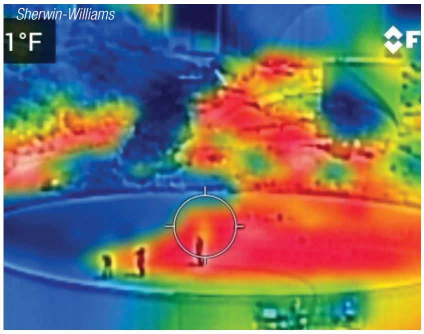


FIGURE 3. An industrial anticorrosion coating under development by Sherwin-Williams serves as its own insulation. Infrared imaging, like the one shown here, illustrates the heat-retention ability of the coating where it is applied (blue color) compared to where it is not (red-orange color)

The newly developed insulative coating allows for a maximum temperature exposure of 177°C (350°F) with excursions to 205°C (400°F) permitted, plus a higher temperature limit anticipated in the future, ac-

LABOR ISSUES

Covestro's Reinstadtler commented on a non-technology-related aspect to the corrosion protection field that has to do with personnel. "There's a profound labor shortage of both skilled and unskilled labor surrounding the corrosion coatings field," he says. And the labor shortage is connected to a drive for higher-durability coatings.

Although polyaspartic (an aliphatic polyurea) technology has been around for awhile, it is now playing an increasing role because of its potential ability to help save labor. Polyaspartic resins are similar to aliphatic polyurethanes, but they have an amine that reacts faster than existing resins, so coatings based on polyaspartics cure faster, Reinstadtler says. With this type of technology, less time is required between coats, and it can be applied thicker, so there are fewer coats required. Often, one coat can be eliminated while still fulfilling the coating-system thickness specification. This saves on labor needs. "Polyaspartics are one of the fastest-growing classes of topcoats right now," he says. ❑

cording to Sherwin-Williams' Crenshaw. "This higher thermal performance rating means the coating can be used on a wide range of heated assets, enabling owners to forgo traditional insulation systems and eliminate the issue of CUI in more applications," he says. Further, the coating's thermal performance is retained over time, in contrast to traditional insulation systems, which lose performance when they become laden with moisture, he adds.

Sherwin-Williams has based the new coating on existing products designed for CUI, but the coating is applied much thicker than any other now on the market, Crenshaw remarks — up to 10 mm dry-film thickness in one or two coats, plus a topcoat to seal and smooth the finish. "At that thickness, the coating retains heat similarly to traditional insulation, as proven in forward-looking infrared (FLIR) imaging taken on a ground storage tank being tested with the coating," Crenshaw says (Figure 3).

Alloying

In a marked departure from other anticorrosion approaches using organic coatings to prevent moisture from contacting a component surface, the company EonCoat LLC (Fuquay-Varina, N.C.; www.eoncoat.com) has taken a fundamen-

FIGURE 4. Technicians use non-destructive testing to detect the presence of moisture, an indication of where CUI may be a problem

tally different approach to corrosion prevention that involves the formation of an inert passivated layer at the carbon-steel surface. Rather than applying a polymeric coating, the EonCoat system chemically bonds with iron at the component's surface to create a protective layer of iron-magnesium-phosphate compounds that are inert, explains EonCoat founder Tony Collins.

On top of this protective alloy layer, EonCoat creates a layer of ceramic material made of phosphates and silicates. "If the alloy layer gets damaged, this ceramic will leach a little phosphate onto the steel and fix the alloy layer," Collins says, adding that the healing mechanism lasts for the life of the asset.

After first introducing a coating for atmospheric corrosion a decade ago, EonCoat more recently introduced a variation of the coating that is specifically designed for CUI. EonCoat CUI/High-Temperature Coating is similar in principle to the original product, but contains additives to resist thermal shock, Collins points out.

Use of the EonCoat CUI coating product has expanded recently, spurred by positive results from field testing by Chevron Corp. (San Ramon, Calif.; www.chevron.com). Chevron tested the EonCoat CUI coating at its Pascagoula, Miss. petroleum refinery and found that the EonCoat system prevented CUI on surfaces that had been intentionally scratched and mechanically damaged after 335 hours of exposure to salt fog.

Collins says the EonCoat system also offers other advantages as well, including an application process that is not affected by high humidity and requires minimal surface preparation, and no concerns about VOCs and hazardous air pollutants.

CUI detection advancements

Another dimension in addressing the problem of CUI at industrial sites is its detection on in-service equipment, piping and structural elements at a plant site. Technological improvements in the methods and instruments that detect the presence of CUI are also making their way to plant sites.

Brian Anderson, director of advanced technologies at the materials testing company Acuren Group Inc. (Webster, Tex.; www.acuren.com), says companies are starting to accept the need to invest in comprehensive CUI programs to avoid costly failures. Among the keys to such a program is ensuring physical access to the assets on the part of technicians. Acuren has pioneered innovative methods to allow roped access by technicians to inspect and test process equipment, pipes, storage tanks and structures.

Once the equipment is accessible, instruments for non-destructive testing (NDT), such as real-time radiography (RTR) and moisture detection imaging, become critical. "For CUI testing, RTR is really taking off at the moment," Anderson says. In RTR, X-ray radiation is used to generate digital images of the outer profile of equipment that is covered by insulation, without the need to remove any insulation. For example, RTR can detect changes to the outer diameter of a pipe that might indicate corrosion.

Acuren is currently developing new versions of its radiography instruments with enhanced capabilities for measuring insulation surfaces that are aimed at increasing the speed and effectiveness of testing while reducing costs, Anderson says.

Since the presence of water is a prerequisite for CUI, NDT methods that can detect moisture, such as Compton backscatter, can be used.

DIGITALIZATION INCREASES THE NEED FOR COATINGS THAT PROTECT ELECTRONICS

Digital transformation initiatives are increasing the need for corrosion resistance of electronic components. "Connected devices require more reliability when deployed in harsh environments," says Ryan Moore, marketing manager for HZO Inc. (Morrisville, N.C.; www.hzo.com). Moore's company is developing a range of nano-engineered coatings for protecting electronic components from corrosion. These coatings allow compact electronics to be coated with thinner layers.

"Conventional coatings may provide reliability, but they must be applied in thick layers to allow a product to be truly dependable. So, the sheer thinness of the coatings are an important performance characteristic," Moore says. Nanoscale engineering also allows for more customization because more materials can be used, he adds.

HZO is developing new coating materials, as well as application processes and equipment for coating components, such as printed circuit boards for computers. Last year, the company received ISO 9001 certification for its facility in Vietnam.

Dow Inc. (Midland, Mich.; www.dow.com) recently introduced Dowsil CC-2588, a tough, abrasion-resistant conformal coating designed to protect printed circuit boards from humidity and corrosion. The silicone-based coating has "extremely low" VOC content and cures at room temperature. "While traditional silicones offer good resistance to humidity and chemicals, they may lack abrasion resistance because of their rubbery nature," Dow says. "However, Dow's new DOWSIL material, once cured, is comparable to other resin conformal coatings in terms of toughness. ❑

As X-rays hit an object, some are absorbed, producing a transmission X-ray image, and others are scattered (Compton scattering). Backscatter images are formed from the X-rays that are scattered back toward the X-ray source. Compton scattering is material-dependent, with the lower-atomic-number materials scattering more strongly than the higher-numbered ones, Hydrogen, being a low atomic number, returns higher Compton backscatter, so areas that have higher levels of hydrogen (from water) can indicate the presence of moisture and can reveal locations that might be susceptible to CUI, Anderson says.

As part of its comprehensive CUI program, Acuren has also developed a proprietary method for moisture detection using the Compton backscatter method, known as Moisture Detection Imaging (MDI). Acuren MDI does not require any insulation removal and can scan large areas rapidly to confirm the presence of moisture without being affected by temperature conditions.

Remotely operated aerial drones are also becoming important tools for screening for and assessing CUI at industrial sites. Jennifer Dowdle, materials engineer and senior inspector at Acuren, says that while drones will not be suitable for all situations, they have been used by Acuren to carry out initial assessments of assets for CUI. In those cases, the drones were outfitted with infrared thermography sensors and ultrasonic probes for performing follow-up thickness measurements, she says. ■

Scott Jenkins

Flow Measurement & Control

Fluid Components International

Endress +Hauser

Krohne Messtechnik

Bükert Fluid Control Systems

Thermal flowmeter supports compressed-air systems

FS10i Series compressed-air flowmeters (photo) helps users improve productivity by measuring accurately and quickly detecting system leaks, which improves overall process quality while simultaneously reducing system energy costs. The compact FS10i flowmeter series measures the flowrate of compressed air, air and natural gas. They are accurate to ±1.5% of reading; ±0.5% of full scale; with repeatability of ±0.5% of reading; and have a response time of 4 s. They are SIL-2 rated for safety instrumented system (SIS) critical processes. Providing precise direct mass-flow measurement, the FS10i flowmeters require no additional pressure or temperature sensors or other components to infer flow measurement. Their sealed and no-moving-parts sensor does not foul or clog, and requires no routine maintenance, which ensures years of trouble-free, continuous operation. — *Fluid Components International, San Marcos, Calif.*
www.fluidcomponents.com

A new line of flowmeter measures more than just flow

The Proline 10 product family (photo) provides time and money savings over the entire product lifecycle without any limitation on measurement performance. Every device is tested on accredited and traceable calibration rigs per ISO/IEC 17025. Proline 10 provides a high level of simplicity, safety and reliability. Both commissioning and operation can be done quickly, in the field, as well as in the control room. A commissioning wizard enables on-site configuration with either the auto-rotatable and high-contrast LCD touch screen, or the SmartBlue app via Bluetooth. The latter approach is particularly useful when devices are installed in difficult-to-access locations. Proline 10 flowmeters cover a wide range of basic applications in all kinds of industries. Proline Promag electromagnetic flowmeters are ideally suited for measuring the flows of conductive liquids, as well as for volume measurement of water and corrosive liquids (Promag W/H/D 10), and chemically aggressive fluids (Promag P 10). Promass K 10 Coriolis flowmeters measure the mass flow of both liquids and gases in utilities, with minimal operating costs to maintain the flowmeter. Proline 10 provides optimum product quality and process monitoring measurements via the simultaneous measurement of additional process variables. In addition to mass flow, Promass K 10 also measures volume flow, temperature and optionally density. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

This ultrasonic clamp-on flowmeter has new features

The ultrasonic clamp-on flowmeter Optisonic 6300 (photo) is now available with new designed stainless-steel sensor rails and an enhanced signal converter for quick and easy setup. The ultrasonic clamp-on flowmeter is suitable for temporary or permanent-mount installation on virtually any pipe up to DN4000, with process temperatures up to 200°C. It allows for flow measurement of non-conductive liquids in main and utility applications where inline measurement is not possible or desirable. The new stainless-steel 316L sensor rails are designed for quick, easy and accurate installations and can be mounted to any pipe within minutes. The same rail type can be used in hazardous areas, in extended temperature applications, in harsh conditions like offshore environments, or as IP68/NEMA 6P version in submerged applications. — *Krohne Messtechnik GmbH, Duisburg, Germany*
www.krohne.com

SAW flowmeter with explosion protection approval

This company's FLOWave flowmeters (photo) are now approved for use in potentially explosive atmospheres. Hygienic measurement without media contacting sensor

elements in the tube is thus also possible in Ex zones with flammable solvents, such as alcohols, for the production of pharmaceutical products, spirits, semiconductors and paints. For a reliable process, quality and production guidelines must be observed and production parameters documented, even with frequent product changes. The FLOWave flowmeter Type 8098 is offered as an ATEX-certified version up to Ex zone 2 for production processes in potentially explosive atmospheres. The flowmeter operates according to the surface acoustic wave (SAW) method. With this measuring principle, there are no dead legs or sensor elements in the measuring tube. The clean- and steam-in-place-capable flowmeters can thus be cleaned just as easily as normal pipelines. — *Bürkert Fluid Control Systems, Huntersville, N.C.*
www.burkert.com

Wheel flowmeter measures high-temperature oils

The TRP Pelton Wheel high-temperature turbine flowmeter (photo) is designed to monitor and control the cooling and process efficiency of high- and ultra-high-temperature oil used in heating and cooling circuits. With accuracies of 2.5% and repeatability of 0.5%, the device provides cost-effective measurement of oil volume flowrates in heating and cooling circuits, even in applications with contaminated or extremely hot media. Four flow ranges are offered across all meter sizes from ½ to 1 in.: 75 to 7.5 gal/min, 2.5 to 25 gal/min, 4 to 40 gal/min and 8 to 75 gal/min. Media temperature range for non-Ex zones is –76 to 662°F and –4°F to 464°F for Ex zones. The meters can tolerate operating pressures up to 290 psi and has a 303 stainless-steel housing. — *AW-Lake Co., Oak Creek, Wis.*
www.aw-lake.com

Explosion-proof flowmeter for liquids, gases and steam

The Fluxus F/G831 ultrasonic flowmeter (photo) measures liquids, gases and steam and is approved for operation in ATEX/IECEx Zone 1. The flow measurement is carried out non-intrusively with ultrasonic transducers mounted on the outside of the pipe. Fluxus F/G831 has two intrinsically safe (Ex-ia) process inputs for connecting pressure and temperature sensors. This allows the transmitter to directly determine the output mass flow or standard volumetric flowrate. The new series of instruments has been developed for demanding measurement tasks in challenging environments. Inside the hermetically sealed enclosure, a digital signal processor ensures the highest measurement performance. The integrated disturbance correction ensures good measurement accuracy, even at unfavorable measuring points. Furthermore, the high-performance processor supports fast switching between two measuring channels. Synchronized channel averaging enables immediate compensation of measured value fluctuations resulting from disturbances of the flow profile due to turbulence or difficult inlet conditions. — *Flexim GmbH, Berlin, Germany*
www.flexim.com

AW-Lake

Flexim

A compact, ultrasonic liquid flowmeter/controller

The new, compact ES-Flow ultrasonic flowmeter/controller Series ES-113C (photo) was designed for the OEM market to measure or dose

Bronkhorst High-Tech

low-volume flows with high precision, high linearity and low pressure drop. Liquid flows from 2 up to 1,500 mL/min can be measured using ultrasound in a small-bore tube. This technology is independent of fluid density, temperature and viscosity, so the instrument does not require recalibration when switching fluids. Thanks to the combination of a straight sensor tube with zero dead volume and transducers positioned at the outer surface, the flowmeter is self-draining and easy to clean. Wetted parts are made of stainless steel, and the exterior design is rated to IP66/IP67. The on-board proportional-integral-derivative (PID) controller can be used to drive a control valve or pump. This makes it possible to establish a complete, compact control loop. Moreover, the instrument features various fieldbus options, customizable I/O functions and temperature as secondary output. — *Bronkhorst High-Tech B.V., Ruurlo, the Netherlands*

www.bronkhorst.com

New actuator enables backwards compatibility

Lifetime Management, the service and maintenance program from this company, has been enhanced by the launch of IQ3 SET (photo), offering backwards compatibility to the 1960s. Lifetime Management helps users manage the risk associated with ageing assets. It includes tiered maintenance options, upgrade services, planned shutdown support and life cycle services. The backwards compatibility offered by the IQ3 SET is appropriate for legacy actuators on sites that have non-integral starters (known as SyncroSET). The IQ3 SET feature facilitates obsolescence management and future-proofs plants without affecting the plant infrastructure. It is a bridge between legacy products (stretching back to this company's A-Range actuators) and investment in the latest actuation technology. It is compatible with existing site cabling and control systems, so there is no need for new cabling and associated costs. There is minimal downtime during upgrades. The IQ3 SET option works with and supports the features of older versions, with seamless integration into existing plant architecture and no need to change existing cables or control systems. IQ3 SET allows access to the many benefits an IQ3 brings to modern plant and network de-

Rotork Plc.

sign, operation and maintenance, ensures continuous reliability, connectivity and performance, and offers advanced IQ3 functionality. Inserting IQ3 technology into a legacy system also brings the benefits of improved connectivity and service support through the wider Lifetime Management program. — *Rotork Plc., Bath, U.K.*

www.rotork.com ■

Gerald Ondrey

New Products

Introducing a large mill-discharge slurry pump

The MDM900 mill-discharge slurry pump (photo) is the latest addition to this company's flagship Mill Discharge (MD) Pump Series. The MDM900 is designed for heavy-duty use in concentrator plants, where capacity and wear-resistance are essential. The MDM900 is an all-metal, thick-walled, extra heavy-duty pump designed for extremely arduous mill-duty applications. The advanced design of the MDM900 enables minimized slurry velocities in the pumps, thus reducing the rate of wear significantly. This translates to increased uptime and productivity, says the company. The pump delivers flowrates up to 13,500 m^3/h (60,000 gal/min) with heads up to 40 m (132 ft). Its impeller has a diameter of 2,100 mm (83 in.) and an inlet size of 900 mm (36 in.) — *Metso Outotec Corp., Helsinki, Finland*
www.mogroup.com

An extractor for valorization of functional nutrients

The Turbex extractor (photo) helps to produce high-quality extracts from botanicals and natural products and to turn waste, such as orange peel or brewer's spent grain (BSG), into revenue-generating nutrients. This patented extraction technology uses a series of rotors and stators to cause thousands of cavitation events per second, resulting in higher yields in shorter processing times. Assisted by a counter-current process, Turbex delivers yields up to 50% higher than conventional systems, says the company. The low extraction temperature combined with the short processing time improves the product quality since oxidization of valuable polyphenols and antioxidants is avoided. Requiring up to 30% less energy than conventional extraction methods, Turbex is said to have a faster return on investment and less environmental impact. — *Andritz AG, Graz, Austria*
www.andritz.com

Swing check valves for fluegas desulfurization

The maintenance-free RSK swing check valves (photo) offer a high functional reliability because a tight shut-off is ensured by a rubber-lined valve disc without rotating parts and without extensions through the body wall. Because all wetted parts are rubber-lined, they are highly resistant to corrosion and abrasion, such as in fluegas-cleaning systems. The swing check valves are fluid-controlled, which means their functionality cannot be manipulated from the outside. In low flowrates — that may occur when operating variable speed pumps — the valve disc remains stable in its position and does not tend to chatter. With their streamlined design, the flow resistance of these valves is up to 45% below that of alternative check-valve types. The valve can be mounted in either a horizontal or a vertical position. The bodies made of nodular cast iron are available in nominal sizes 25 to 300 and designed for a nominal pressure of 16 bars. — *Sisto Armaturen S.A., Echternach, Luxemburg*
www.sisto-aseptic.com

This silencer helps protect workers from gas process noise

The Fisher WhisperTube Modal Attenuator (photo) was introduced recently for noisy gas or vapor applications. The modal attenuator is a full-bore device offering 15-dB sound suppression to reduce noise inside pipes produced by sources upstream, such as control valves, pressure-relief valves, pumps, compressors and other devices that generate noise. It is installed downstream of these types of devices in place of a pipe spool piece, generates no additional pressure drop and has no impact on process flow. WhisperTube devices are offered in sizes from 2 to 12 in., with AMSE flange ratings of Class 150, 300 and 600. Pressure ratings match the flange rating sizes, and the maximum temperature is 700°F. — *Emerson Automation Solutions, Marshalltown, Iowa*
www.emerson.com

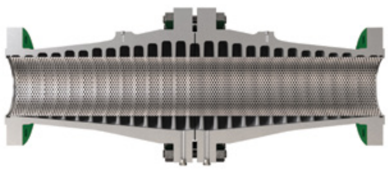
This heat exchanger provides 330°F air for drying process

The custom designed three-stage heat exchanger (photo) will be used to increase temperature of a 25,000 std. ft^3/min airflow from 50°F to


Metso Outec


Andritz


Sisto Armaturen


Emerson Automation Solutions

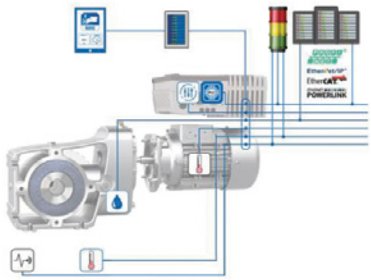

Xchanger

TensionPro

330°F using 145 psig steam. Each stage is nearly 7 ft tall and 8 ft wide. Heated air will be used to dry crumb rubber during processing. The design uses seven identical internal cores, each with two stacked steam circuits. — *Xchanger Inc., Hopkins, Minn.*
www.xchanger.com

These bolt washers are also tension sensors

This company has introduced a range of ultra-low profile bolt-load washers that is ideal for bolt-load and tensioner tool calibration. Called TensionDisc (photo), the washers are specially designed load sensors that monitor bolt loads in bolted joint assemblies. A simple handheld reader with a wired or infrared connection allows for simple reading of the bolt load. These data can be exported via USB to a PC. Optional connectivity options allow for multiple uses of the data. Accurate and reliable for long-term use, as well as very easy to set up, TensionDisc is available for bolt sizes M20 to M72 (and inch equivalents). Special designs are also available on request. — *TensionPro, Norton Canes, U.K.*
www.tensionpro.co.uk



Nord Gear

Condition monitoring for optimizing drive systems

Condition monitoring for predictive maintenance (photo) is a drive solution that focuses on status-oriented maintenance rather than traditional time-based maintenance. Status and drive data are recorded periodically or continuously via the programmable logic controller (PLC) output parameters and can be viewed or saved to a local dashboard via an Industrial Ethernet protocol such as EtherNet/IP. The collected data are analyzed and used to detect any suboptimal operating conditions so that machines and systems can be proactively maintained, and unplanned downtimes can be avoided. In addition to digital and analog sensors that monitor internal values, the drives can also evaluate external conditions with temperature and vibration sensors. — *Nord Gear Corp., Waunakee, Wis.*
www.nord.com

Biotage

A pair of evaporators for well plates

The TurboVap 96 Dual (photo) is a second-generation well plate evaporator system with two separate, and independently controlled evaporation compartments. The TurboVap 96 Dual has been designed to support enhanced well-plate evaporation within the sample-preparation workflow. With its unique two-in-one functionality, users can run the same method on two plates simultaneously, or two independent evaporations, essentially doubling throughput. The capability to act as two single units and a dual enables laboratories an opportunity to balance their evolving sample throughput needs. TurboVap 96 Dual is dedicated to the evaporation of solvents in 24, 48, or 96 well-plate-array formats. The system can evaporate solvent levels from microliters up to 10 mL per well. The system applies user controlled heated nitrogen from the top, while simultaneously heating the bottom of the well plate by convection. Evaporated solvent vapors are contained and evacuated under negative pressure. — *Biotage GB Ltd., Ystrad Mynach, U.K.*
www.biotage.com

WAGO

A compact controller with integrated I/Os

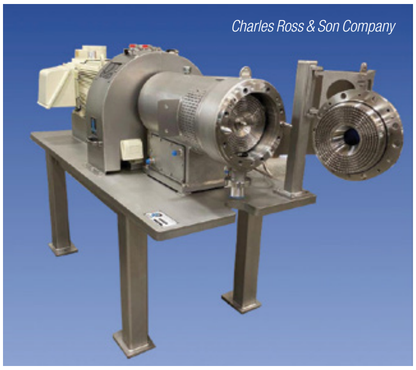
The Compact Controller 100 (photo) is a small controller with integrated input/outputs (I/Os) that is suited for smaller automation solutions. Thanks to its design as a DIN-rail built-in installation device according to DIN 43880, the new controller can also be mounted in small distribution boards. The I/O unit is housed with the controller in a compact enclosure, so it requires no additional space for other control components. The wiring interface is removable, which is advantageous for installation and facilitating device replacement. The Compact Controller 100 can be freely programmed according to IEC 61131 with CODESYS V3. Extensive IEC libraries and macros simplify the process of creating applications. The compact controller uses a real-time Linux operating system and supports standard fieldbus protocols. — *WAGO GmbH & Co. KG, Minden, Germany*
www.wago.com

Modular plug connectors for use in hazardous areas

This company has launched a new generation of plug connectors with the Ex e and Ex d types of protection for quick connection of explosion-

protected electrical equipment. As a solution that is particularly easy to mount and maintain, the modularly designed miniCON series (photo) offers a wide range of options, which can be designed for in-line connection of portable control systems, electrical systems, moving machines and drives, as well as camera and human-machine interface (HMI) systems. The eight-pole plugs and couplings are designed for cable cross-sections from 0.25 to 2.5 mm². — *R. Stahl AG, Waldenburg, Germany*
www.r-stahl.com

Ultra-high shear mixer for sanitary applications



The Model HSM-409XSHD-125 (photo) is a clean-in-place (CIP)-capable sanitary mixer featuring a type 316 stainless-steel mixing chamber, a 150-psig jacket for cooling and heating up to 250°F, and an X-5 Series 9-in. dia. AL6XN stainless-steel rotor/stator that operates up to 5,700 rpm). The X-Series mix head is a patented design made up of concentric rows of intermeshing teeth. Product enters at the middle of the stator and travels outward through the radial channels. Every pass through the rotor/stator exposes the product to tremendous shear due to the combination of very tight tolerances and extremely high tip speeds. Compared to traditional colloid mills, the X-Series routinely achieves a higher reduction in droplet or agglomerate size, says the company. — *Charles Ross & Son Company, Hauppauge, N.Y.*
www.mixers.com

Fire-rated buildings for storing chemicals

The new Rack Fire Protect (RFP) buildings (photo) are fire-rated for 2 h at 2,192°F (1,000°C), minimizing the risk of fire spreading within the workplace. Designed in Germany and proven in hundreds of installations worldwide, they are

now manufactured in the U.S. for North American installations. The buildings provide safe and legally compliant storage of flammable and corrosive chemicals. Adjustable racking provides the flexibility to store up to forty-eight drums or twelve intermediate-bulk containers (IBCs). Single or double-tiered designs keep dangerous chemicals organized and correctly separated. RFP buildings are built in accordance with FM Approval 6049, NFPA, OSHA, EPA-CFR 40, NBCC, NFCC and ETA/21/0642. — *Denios, Inc. Louisville, Ky.*
www.denios-us.com

Container mixer sets new standards in safety, productivity

The CMQ container mixer (photo, p. 24) supplies a product that meets the requirements for mixing quality, dispersion, efficiency and safety. This is proven by the recently issued E.U.-type examination certificate according to ATEX Directive 2014/34/EU, meaning that the CMQ container mixer is approved for mixing bulk materials that require a design in equipment

category 1/3 D (zone 20 inside, zone 22 outside). The patented CMQ container mixer can also meet the requirements of dust-explosive

substances, thus making inerting obsolete. In addition to meeting high safety standards, the CMQ container mixer guarantees very high dispersion thanks to its innovative design. The airfoil mixing tool in combination with the winglets ensures good formation of the mixing stream, fast material movement and keeps mixing resistance low. This protects the products and can reduce the temperature rise to a minimum, for example by a maximum of 2°C/min for a powder-coatings premix. — *Zeppelin GmbH, Garching near Munich, Germany*
www.zeppelin.com

A new product enables remote machine monitoring in real time

Smart Connected Product (photo) is a new, IIoT (industrial internet of things) solution that connects production machines at any facility and

visualizes relevant information on a single platform. These data can be viewed over the web on any device with a secure connection and is accessible only to authorized users. The integrated solution addresses the evolving needs of the healthcare industry, enabling pharmaceutical and nutraceutical companies to remotely monitor production machine settings, performance parameters, machine downtimes and alarms over the Smart Connected dashboard — all in real time. — *ACG, Mumbai, India*
www.acg-world.com ■

Gerald Ondrey

Respiratory Protection Equipment Types

Department Editor: Scott Jenkins

Chemical process industries (CPI) facilities often present a number of potential respiratory hazards, including airborne particles, toxic chemicals and low-oxygen environments, that may require the use of respiratory personal-protective equipment (PPE). This reference outlines the major categories for respiratory protection commonly used in industrial production settings.

Particulate respirator

Particulate-matter respirators are essentially mechanical filters and are often the least expensive respiratory protection devices. Particulate-matter respirators are made from nonwoven polypropylene fibers and are designed to prevent particles, such as dust and mist (liquid droplets suspended in air) from entering breathing passages. They are not designed to protect against chemicals, gases or vapors, and are intended only for low-hazard levels.

Within regulations to certify the selection and use of air-purifying particulate respirators, the National Institute of Occupational Safety and Health (part of the U.S. Centers for Disease Control and Prevention; www.cdc.gov/niosh) has established three designations for filter efficiency and three categories for filter efficiency degradation. The filter efficiency refers to the percentage of particles greater than a given size that are removed from air. The designations are 95%, 99% and 99.97%.

A commonly known particulate-matter filter is the N95 filtering facepiece respirator (Figure 1). N95 masks are so-called because they remove 95% of airborne particles 0.3-microns and larger in size. Some N95 masks have a valve to reduce breathing resistance during exhalation. The "N" refers to the mask's resistance to oil. N stands for "not resistant to oil." The other two categories are R (resistant to oil) and P (oil-proof).

FIGURE 1. Particulate respirators, like the N95 mask shown here, are made from non-woven polymer fibers

Chemical cartridge respirator

Chemical cartridge respirators (gas masks) use replaceable chemical cartridges or canisters to remove hazardous gas and vapor contaminants from the air. This type of respirator can be a half-mask (Figure 2; nose and mouth covered), or a facepiece (covers eyes also) that are secured to the head with straps. Air passes through a cartridge or canister, which filters hazardous gases and vapors from air by various means, including absorption, adsorption and chemisorption, depending on the type of substance being removed. Chemical cartridges may also have a filter for solids as well.

Gas masks are effective only if used with the correct cartridge or filter (these terms are often used interchangeably) for a particular biological or chemical substance. Cartridges are available that protect against more than one hazard, but there is no "all-in-one" cartridge that protects against all substances.

A color-code scheme is used to aid in selection. For example, a canister coded white is designed for acid gas, while a green code means the canister is for ammonia. Other color designations include blue (carbon monoxide), black (organic vapors) and purple (radioactive materials).

Powered respirators

Powered air-purifying respirators (PAPRs) use a battery-powered fan to draw air through the filter to the user's nose and mouth. They consist of some type of headgear (either a facemask or a hood), as well as a motor-driven fan that forces ambient air into the device, and some type of filter to remove contaminants from the air before it reaches the mouth and nose. PAPRs are easier to breathe through than gas masks and nonwoven fiber masks, but they require a fully charged battery to work properly. They use the same type of filters/cartridges as other air-purifying respirators, so it is equally essential to know which hazards are present, and at what concentration, in order to select the proper type of cartridges.

FIGURE 2. Chemical cartridges remove hazardous gases and vapors from breathed air

Self-contained breathing

Self-contained breathing apparatus (SCBA) systems use a dedicated air tank to supply clean air to the user, so no filters are required. This type of respiratory protection is capable of protecting against higher concentrations of dangerous chemicals. However, a SCBA system is heavy (30 pounds or more), and requires special training on how to use and maintain it. A typical SCBA air tank lasts about an hour or possibly less, depending upon the rating of the SCBA and the breathing rate and intensity of the user. ■

Resources

OSHA, General Respiratory Protection Guidance for Employers and Workers, U.S. Occupational Safety and Health Administration, OSHA Bulletin, 2011.

California Department of Industrial Relations, Respiratory Protection in the Workplace: A guide for employees, updated April 2021, accessed online at: www.dir.ca.gov/DOSH/DOSH_Publications/respiratory-protection-employer-guide.pdf.

Production of L-Lysine

By Intratec Solutions

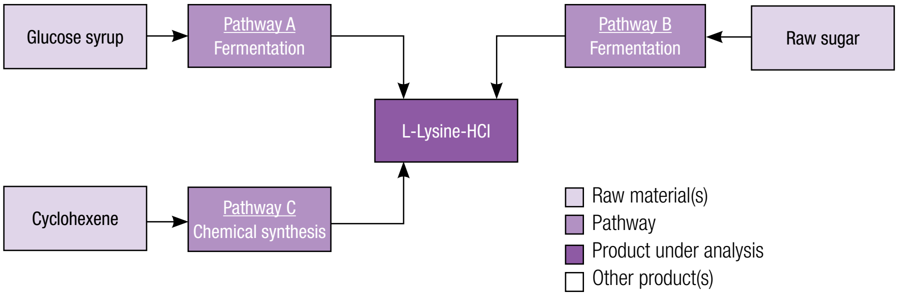


FIGURE 3. Several pathways for making L-lysine exist, including fermentation and chemical synthesis, which is less common

Lysine (Figure 1) is an α-amino acid used in the biosynthesis of proteins. The compound contains an amino group and a carboxylic acid group. Under biological conditions, the amino group is protonated ($–NH_3^+$) and the carboxylic acid group is deprotonated ($–COO^-$).

The α-carbon of lysine is a chiral center, so two enantiomers of the compound exist. Only L-lysine is biologically active. Lysine is an essential amino acid that must be supplied through the diet. It is commercially produced as L-lysine monohydrochloride (L-lysine·HCl) and L-lysine sulfate. L-lysine·HCl is a yellowish-white, crystalline powder, mainly used as a food and feed supplement. Other uses relate to cosmetics, human medicine, culture media and pharmaceuticals.

Lysine is produced from raw sugar (sucrose) using a conventional fermentation process in which raw sugar is hydrolyzed into glucose and fructose (invert sugars). The invert sugars are then fermented to produce L-lysine, which is recovered via ion-exchange adsorption.

Process

Fermentation-based lysine production from raw sugar is similar to the Archer-Daniels-Midland process, and comprises three major sections: (1) fermentation; (2) product recovery; and (3) product concentration, drying and packaging (Figure 2).

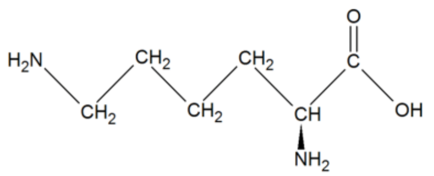
Fermentation. The culture media used in fermentation is prepared by mixing process water, invert sugar and nutrients. The fermentation is performed in fed-batch mode and under aerobic conditions. To start the batch phase, the microorganism seed is fed into the fermenters, which were previously filled with the fermentation batch medium. After glucose exhaustion, the batch phase is finished and the fed-batch phase is started, during which, glucose and nutrients are continuously supplied until the desired L-lysine concentration is achieved. At the end of the fermentation, the broth is sent to a buffer tank to provide a continuous flow in the further process steps.

Product recovery. The fermentation broth is sent to an ultrafiltration system for the removal of cell debris and other suspended solids. Subsequently, the liquor from ultrafiltration is fed to ion-exchange columns, where L-lysine is selectively adsorbed. The adsorbed L-lysine is then eluted from the ion-exchange resins by washing with an aqueous ammonia solution.

Product concentration, drying and packaging. The L-lysine eluate from ion exchange columns is mixed with mother liquor from the product filtration step and concentrated by evaporation. The concentrated lysine solution is acidified with hydrochloric acid, and free L-lysine is converted to L-lysine·HCl. Subsequently, the L-lysine·HCl solution is sent to the crystallizer, and lysine salt is filtered. The mother liquor is recycled to the evaporator and the wet cake is conveyed to dryers. Final dry L-lysine·HCl (98.5 wt.%) is obtained and sent to packaging line before being stored in bags. L-lysine is hygroscopic, so it must be stored in tightly sealed containers tightly in dry, cool conditions.

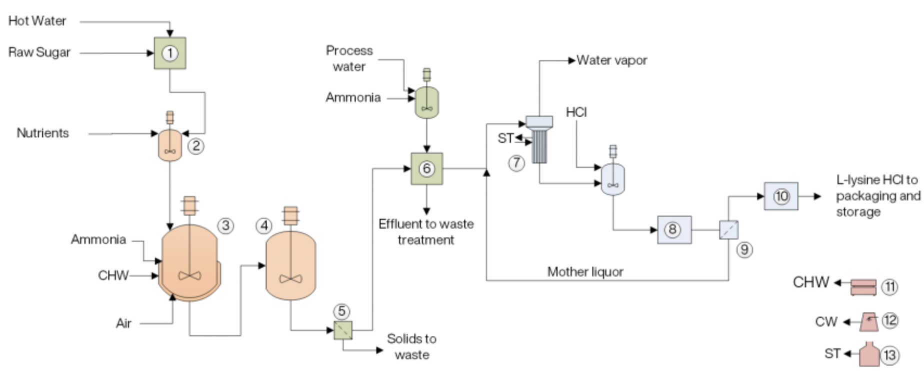
Pathways and uses

The L-lysine·HCl process involving sugar fermentation is accomplished by modified microorganisms. The sugar used in the bio-based chemical route can be derived from sugarcane, beet or corn. L-lysine can also be produced from cyclohexene via a chemical pathway. However, only a few plants use this alternative (Figure 3).



L-Lysine

FIGURE 1. L-lysine is an essential amino acid with a chiral center



1. Sugar inversion
2. Medium vessels
3. Fermenters
4. Buffer tank
5. Ultrafiltration unit
6. Ion-exchange unit
7. Evaporator
8. Crystallizer
9. Product filter
10. Dryer
11. Chiller
12. Cooling tower
13. Steam boiler

CW Cooling water
ST Steam
CHW Chilled water

FIGURE 2. The diagram shows the production process for L-lysine

Editor's note: The content for this column is developed by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are based on publicly available and non-confidential information. The content represents the opinions of Intratec only.

Crystallization for Ultra-Pure Chemicals

Optimized crystallization units can help address the challenges posed by product-purity requirements in the battery industry

John Warner and Nipen Shah
JordProxa

IN BRIEF

CRYSTALLIZATION TECHNOLOGIES

PRODUCT PURITY

PURITY ENHANCEMENT FACTORS

THE BENEFITS OF LARGE CRYSTALS

CONTINUAL IMPROVEMENT IS KEY

Crystallization is a key purification process that has been used for decades to refine sugar, produce essential pharmaceuticals and recover valuable salts. Producers of chemicals for applications that demand ultra-high purity, such as rechargeable batteries, which require extremely pure nickel, cobalt, manganese and lithium, are now turning to crystallization technologies to meet continually increasing purity requirements.

In recent years, a rapid increase in demand for electric vehicles has fueled fast product advancements. As a result, the cost of battery storage decreased by a factor of six in just five years.

From this period of development, the nickel-manganese-cobalt (NMC) chemistry blend emerged as the top-performing blend for lithium-ion battery performance. Furthermore, automakers learned that the key to mass adoption of electric vehicles is affordable range. This is best achieved by increasing the energy density of the batteries through a higher ratio of nickel in the blend. However, an increased amount of nickel in the batteries comes with a greater risk of the batteries overheating due to traces of impurity present in the nickel-containing battery chemical (nickel sulfate hexahydrate; $NiSO_4 \cdot 6H_2O$). To ensure there are no extraneous components that will cause the batteries to overheat, it became critical to use ultra-pure battery chemicals.

The challenge for the nickel sulfate industry today, as it strives to meet the rapidly increasing demand for nickel, is to achieve the exceptionally high purity levels that are required for high energy density in batteries. A well-designed crystallizer is emerging as the critical technology for meeting such purity requirements. Figure 1 shows a crystallizer unit that was designed to deliver nickel sulfate hexahydrate.

This article reviews the aspects of crystallization technology that particularly impact the purification of chemicals, and identifies challenges that operators must overcome, as well as key design features that can be optimized to overcome these challenges. This article uses battery-grade nickel sulfate hexahydrate as an example, but the principles could be applied to the purification of other ultra-pure chemicals as well.

Crystallization technologies

There are three major types of crystallizers in service today. They are described below:

- Forced circulation (FC) crystallizers, which rely on crystallization in a mixed suspension, may either incorporate mixed product removal or classified product removal
- Fluidized-bed, or Oslo, crystallizers, in which natural circulation is used to enable fine crystals to be separated by size
- The draft-tube baffle (DTB) crystallizer, in which forced circulation is used to enable fine crystals to be separated by size

This article focuses on qualitative insights that are or particular relevance to battery chemicals. How the configurations of the three types of crystallizers impact the formation and growth of crystals is discussed in Ref. 1. Table 1 provides a high-level comparison of the three different types of crystallizers [*2*].

Oslo and DTB crystallizers are both designed to produce larger crystals than the FC type by: (a) managing the circulation of slurry to avoid excessive supersaturation; and (b) providing a means of separating fine crystals, which can then be preferentially circulated to the heating loop. The first of these features helps prevent nucleation. The second helps destroy any fine crystals that are formed by re-dissolving them into the mother liquor as it passes through the heating loop. Acting together, these two features narrow the particle-size distribu-

FIGURE 1. Due to crystallizers' unique abilities to deliver high-purity chemicals, they are being frequently deployed to purify critical battery materials, such as nickel sulfate hexahydrate

tion and increase the mean particle size. It is not possible to incorporate these features into the FC design, where the full inventory of slurry is well mixed.

The following must also be considered in order to grow and recover large crystals:

- Mixing within the crystallizer should be as gentle as practically possible to reduce damage to crystals. Larger crystals will become damaged due to momentum changes within the crystallizer. However, mixing must be sufficient in order to suspend the largest of the crystals and transport them to the boiling surface (zone where the highest level of supersaturation exists)
- Fines will be generated from natural breakage (or chipping) of crystals, as well as by spontaneous nucleation from the supersaturated solution
- Although fines destruction increases the average size of the crystal population, it significantly reduces the available surface area for deposition of new solid matter. Too little surface area can lead to a sudden burst of spontaneous nucleation
- Sufficient time must be allowed in the magma (semifluid) phase for the growth of large crystals
- Classification (or elutriation) of the product removed from the crystallizer enables only the largest fraction to be removed. Fines are returned back to the crystal magma

In the extreme case where high rates of fines destruction and very efficient elutriation legs are employed to generate very large crystals (greater than 2 mm in diameter), there is a risk that the surface area of the crystal population will be insufficient to absorb the fresh solids leaving solution. Spontaneous nucleation can occur, resulting in a sudden drop or "crash" of the average crystal size. Plant operators have learned to avoid the population "crashing" by adding mid-sized crystals to the crystallizer as "seed" to provide additional surface area.

Product purity

Since the development of NMC batteries with high nickel content, there has been increased focus on the purity of nickel sulfate. In particular, a de-facto standard of four nines purity (99.99% w/w) has been adopted for nickel sulfate hexahydrate destined for use in lithium-ion batteries. That allows a maximum of 100 mg of impurities per kg of nickel sulfate hexahydrate product.

Nowadays, serious consideration is even being given to achieving five nines purity. That would allow just 10 mg of impurity per kg of nickel sulfate hexahydrate product. Meeting these product standards presents serious challenges for nickel refiners. However, a properly designed crystallizer can play an important role in helping to achieve four, and then five nines product purity and will greatly ease the requirements imposed upon the upstream refining steps.

To better understand the role a crystallizer can play, it is useful to consider the various ways a crystal can become contaminated with impurity.

A crystal is a three-dimensional matrix of atoms arranged in an orderly sequence. Theoretically, it should be possible to produce a pure compound by growing the crystals from a suitably saturated solution and then separating them. However, in practice, there are several ways impurities can be included either onto or within the crystal matrix, as shown in Figure 2. These were classified in a recent investigation by Urwin and others [*3*]. They identified five principal mechanisms based on the location of the impurity within the crystallization product: agglomeration; surface deposition; mother liquor inclusions; co-crystal formation; and solid solution formation.

Co-crystal formation and solid-solution formation are controlled by the chemistry of the solution, which in large part is determined by the composition of the feed to the crystallizer. We can consider this to be the responsibility of the upstream refining process, although it is acknowledged that there is a need to provide feedback about the composition of the concentrated mother liquor, which will be derived from the feed when the crystallizer reaches

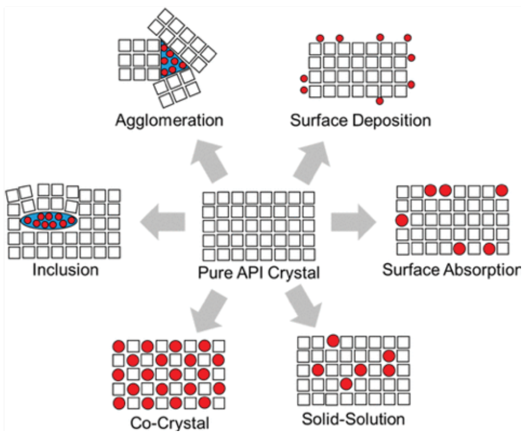


FIGURE 2. There are several inclusion mechanisms for impurities associated with crystallization

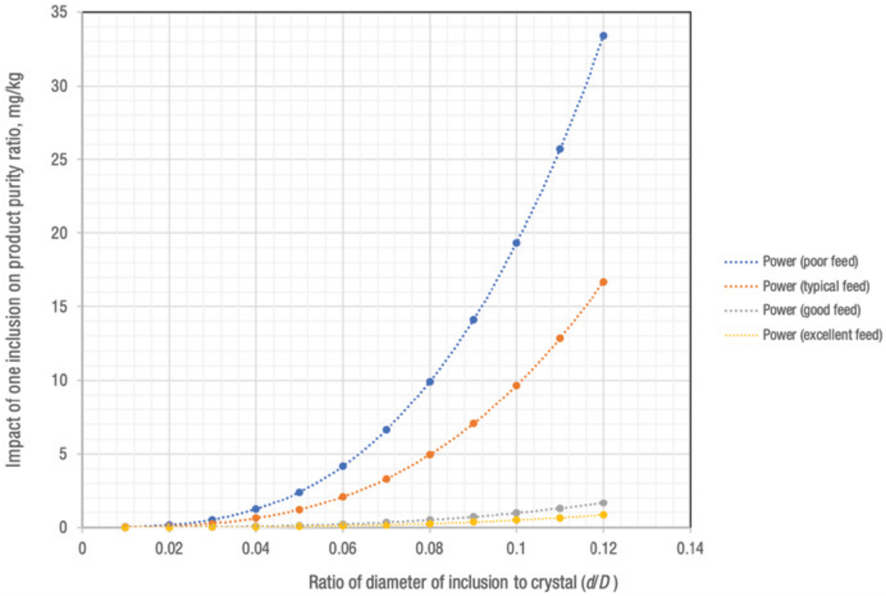


FIGURE 3. The ratio of mass of impurity in the inclusion to the mass of the crystal is plotted versus the ratio of the diameter of the inclusion to the diameter of the crystal

steady state. Therefore, our focus is on the mechanisms that are directly controlled by the crystallization process — agglomeration, surface deposition and mother liquor inclusions.

Agglomeration. When particles aggregate during a crystallization process to form larger agglomerates, pockets of impurity-rich mother liquor can become trapped between the particles. Agglomeration can be prevented by operating with a low degree of supersaturation and paying careful attention to the circulation patterns of liquor within the crystallizer.

Surface deposition. The amount of mother liquor that is entrained on the crystal surface decreases relative to the crystal mass as the diameter of the crystal increases. A high-efficiency wash can be used on a pusher centrifuge to dilute the concentration of the mother liquor by a factor of five or more, thereby further reducing the amount of impurity entrained on the crystal product.

Inclusions. If crystals grow too fast, then impurity-rich mother liquor can become trapped within the growing crystal. Measures can be taken to restrict the rate of growth, but sometimes it is inevitable. It is possible to determine the impact of these inclusions based on the ratio of the diameter of the inclusion to that of the crystal. The case of nickel sulfate hexahydrate, a common battery chemical, is considered as an illustrative example.

A nickel sulfate crystallizer will typically operate with a mother liquor concentration up to 20 times that of the feed. It is convenient to express the concentration of impurity in the feed relative to nickel as the equivalent amount of nickel sulfate hexahydrate, which is the desired product. The concentration can range from as low as 50 mg/kg to as high as 2,000 mg/kg, depending on the upstream process to remove impurity. General purity considerations are detailed below:

- A poor feed has 2,000 mg/kg of impurity
- A typical feed has 1,000 mg/kg of impurity
- A good feed has 100 mg/kg
- An excellent feed has 50 mg/kg of impurity

In Figure 3, the ratio of mass of impurity in the inclusion to the mass of the crystal is plotted versus the ratio of the diameter of the inclusion to the diameter of the crystal. If the desired product purity is four nines, then a ratio of 10 mg of impurity per kg of product is significant, because this represents 10% of the maximum allowance. For the typical feed, this is achieved once the ratio of diameters exceeds 0.1. We typically grow nickel sulfate hexahydrate crystals with an average size of 1,200 µm using a DTB crystallizer. Thus, an inclusion would have to exceed a 120-µm dia. to have a significant influence on the desired purity. In practice, inclusions of this size are rarely observed. The impact of inclusions upon nickel sulfate hexahydrate purity is therefore not considered to be significant at the four nines level for feeds that are typical or better. For the poor feed, the effect of an inclusion becomes significant if the ratio of diameters exceeds 0.08, equivalent to a 96-µm inclusion for the product from a DTB crystallizer. Inclusions smaller than 100-µm are sometimes observed with consequent impact on purity.

If the desired product purity is five nines, then a ratio of 1 mg of impurity per kg of product is significant, because this represents 10% of the maximum allowance. For the typical feed, this is achieved once the ratio of diameters exceeds 0.05, which is equivalent to a diameter of 60 µm. Whereas for the good feed, this is achieved once the ratio of diameters exceeds 0.1, which is equivalent to a diameter of 120 µm. Consequently, the impact of inclusions upon product purity may become significant at five nines purity for feeds containing more than 100 mg/kg of impurity.

TABLE 1. COMPARISON OF CRYSTALLIZER DESIGNS [*2*]

	Forced circulation (FC)	Oslo (Growth)	Draft-tube baffle (DTB)
Operability	Excellent	Satisfactory	Good
Crystal size	Poor	Satisfactory	Excellent
Energy requirements	Good	Good	Better
Typical operating solids in suspension	20 to 25%	50% (In settling zone)	30 to 40%

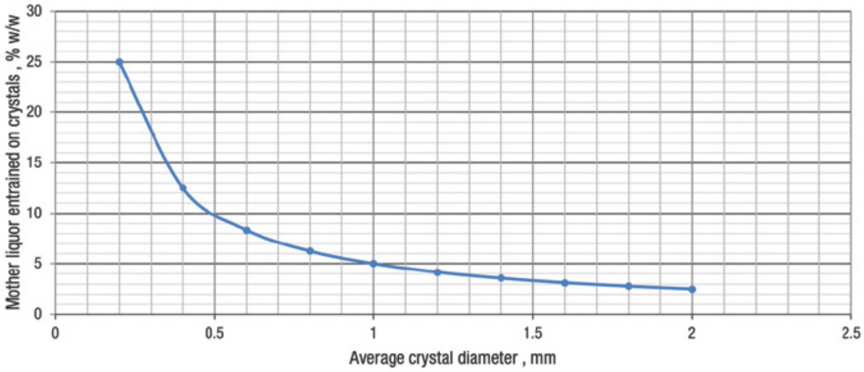


FIGURE 4. This plot shows that the mother liquor that is entrained on the crystals increases markedly as crystal size decreases

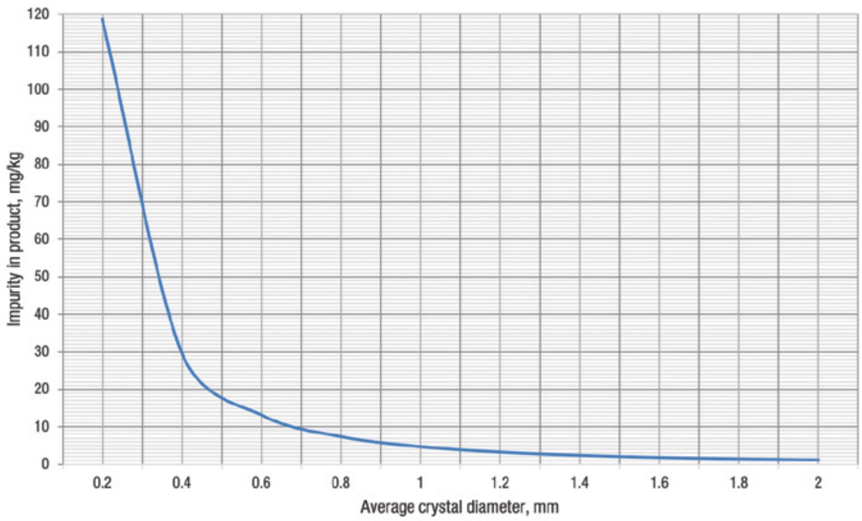


FIGURE 5. As the crystal diameter decreases below 1 mm in diameter, the amount of impurity in the product increases relatively quickly

Purity enhancement factors

It is useful to measure crystallizer performance in terms of the improvement in the mass ratio of impurity to desired crystal product.

In a well-designed crystallizer, the impact of agglomeration and inclusions is negligible. The amount of impurity present in the surface deposition (or entrainment) can be determined from a relatively straightforward mass balance, where the impurity in the feed is equal to the summation of the following:

1. Impurity leaving in the purge
2. Impurity in the entrained liquor
3. Impurity in the condensate
4. Impurity in the dryer vent

The latter two are minor flows and may be disregarded in the calculation of the steady-state concentration of impurity in the mother liquor.

Once the steady-state concentration of impurity in the mother liquor is known, then the amount of impurity in the entrained liquor on the crystals may be determined. It is this impurity that is ultimately dried on the crystal surface, and that contaminates the product.

The crystallizer performance is measured by dividing the ratio of impurity to nickel sulfate hexahydrate in the feed, by the ratio of impurity to nickel sulfate hexahydrate in the product.

To demonstrate the impact of feed on crystallizer performance and purity, two different crystallizer designs were analyzed to represent the current standard design versus an optimized design scenario for enhanced outcomes [*4*]. In an optimized design, the rate of purge is increased, the efficiency of the centrifuge is improved to reduce entrainment and efficiency of the cake wash function at the centrifuge is increased to further dilute the impurity in the entrained liquor. The results of the analysis are given in Table 2. In summary, a performance-enhancement ratio of 10 is achieved by the current, and an enhancement ratio of 40 by the optimized design.

The analysis shows that current crystallizer technology is capable of achieving four nines purity when the feed is of typical purity and five nines purity when it is good or better. However, it cannot achieve four nines purity when the feed is of poor grade.

On the other hand, the optimized crystallizer technology is capable of achieving four nines purity on poor feed grade. The challenge for the future is to develop crystallizer technology capable of achieving five nines purity on typical feed for which a crystallizer performance ratio of 70 or better will be required.

The benefits of large crystals

A simplified analysis based on surface area shows that the benefits of growing large crystals are significant. Consider a population of one million crystals of 1-mm dia. The total surface area is 3.14 m^2 and the total mass of the population is 1,084 g for a density of 2,070 kg/m^3 corresponding to nickel sulfate hexahydrate. At 5% entrainment of mother liquor on the crystals, there will be 54.2 g of mother liquor on the surface of the crystals. Taking the density of the mother liquor at 1,400 kg/m^3, the average thickness of the liquor layer on the crystals will be 12.3 μm.

It is reasonable to assume that the thickness of the liquor film on the crystals after centrifuging at given conditions in a pusher centrifuge is relatively constant. In which case, it has been demonstrated that the mother liquor entrained on the crystals increases markedly as crystal size decreases [*5*]. This phenomenon is shown in Figure 4.

Using a mass balance for the crystallizer system, the concentration of impurity in the liquor at steady state may be determined for a given entrainment on the product crystals if the purge flow and wash efficiency are known. Once the concentration in the liquor is known, the amount of impurity that remains on the product crystals at different levels of entrainment is readily calculated. Typically, a

TABLE 2. PRODUCT PURITY FOR DIFFERENT TYPES OF FEEDS TO NICKEL SULFATE CRYSTALLIZERS

FEED	CURRENT CRYSTALLIZER TECHNOLOGY				OPTIMIZED CRYSTALLIZER TECHNOLOGY			
Design parameters								
Ni in feed, g/L	180				180			
Purge, % of feed	5				10			
Entrainment, % w/w	5				3			
Wash efficiency, %	80				85			
Feed type	**Poor**	**Typical**	**Good**	**Excellent**	**Poor**	**Typical**	**Good**	**Excellent**
Impurity in feed relative to $NiSO_4 \cdot 6H_20$, mg/kg	2,000	1,000	100	50	2,000	1,000	100	50
Impurity in feed relative to Nickel, mg/kg	8,951	4,475	448	224	8,951	4,475	448	224
Impurity in feed , mg/L	1,611	806	81	40	1,611	806	81	40
Crystallizer performance								
Ratio of impurity in feed to that in product	10	10	10	10	40	40	40	40
Product purity								
Impurity in product relative to $NiSO_4 \cdot 6H_20$, mg/kg	200	100	10	5	50	25	2.50	1.25
Impurity in product as mg per 100 mg	0.020	0.010	0.001	0.001	0.005	0.003	0.000	0.000
Purity of product $NiSO_4 \cdot 6H_20$, % w/w	99.980	99.990	99.999	99.9995	99.995	99.998	100.000	100.000
Product purity designation	3 nines	4 nines	5 nines	5 nines	4 nines	4 nines	5 nines	5 nines

crystallizer will operate with a purge flow that is set to no more than 5% of the desired product and wash efficiency on the centrifuge that dilutes the entrained mother liquor by a factor of five or more. These limiting values were used to determine the predicted amount of impurity in the product versus the average diameter of the crystals. The results plotted in Figure 5 show that as the crystal diameter decreases below 1 mm diameter, the amount of impurity in the product increases relatively quickly.

Continual improvement is key

Crystallization is critical to meeting the benchmark for purity in battery chemicals. However, if crystallization is to be an acceptable part of the supply chain for electric vehicle makers, it must also meet the benchmarks for sustainability and value. Tesla has set benchmarks for the industry, which have been widely endorsed by other electric vehicle and battery makers:

- *Purity* — Battery chemicals must be free from impurities to allow high energy density to be safely achieved.
- *Sustainability* — The sustainability of producing battery chemicals must be consistent with the "green" credentials of the vehicles that the chemicals will help power.
- *Value* — The ratio of performance to cost must increase with time to help drive increased consumer demand.

When used well, it is clear that crystallization technology achieves the high degree of purity that is required to maximize energy in lithium-ion batteries. To stay at the forefront, battery-chemical producers, the minerals processing industry, and their technology partners must continue to realize efficiencies that lower costs and deliver increasing value. They must also leverage green energy sources to offer a lower carbon footprint for how to build and operate the plant. ■

Edited by Mary Page Bailey

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Further reading

For more information on crystallization, please read the following articles:

1. Crystallization: Contributing to Circularity, *Chem. Eng.*, March 2021.
2. Moisture Measurement in Solid Materials, *Chem. Eng.*, January 2021.
3. A Simplified Approach to Crystallization Mass Balances, *Chem. Eng.*, July 2020.
4. Nucleation Phenomena in Crystallization, *Chem. Eng.*, May 2020.
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Smarter Chemical Recovery in Pulping Facilities

Evaporation and crystallization technologies have the ability to create advantages for pulping facilities by improving operational efficiency and reducing waste, while simultaneously producing high-value product streams

Scott Silverstein and Michael Begley
Veolia Water Technologies

IN BRIEF

CHEMICAL RECOVERY AND ASH TREATMENT

CHLORIDE REMOVAL PROCESS

PRODUCING SOP

The emergence of new products and markets is driving a global renaissance of the pulp-and-paper industry due to increased global demand for cardboard and paper packaging products, as well as the rise in the need for hygiene products, such as paper towels, tissues and nonwoven wipes. To adapt to these drivers and meet this steep demand increase, pulp producers and integrated paper manufacturers have been racing to expand their pulping operations. In addition to these increased production demands, producers are also feeling pressure from regulatory agencies, as well as consumers, to continually identify process improvements to enhance their sustainability efforts.

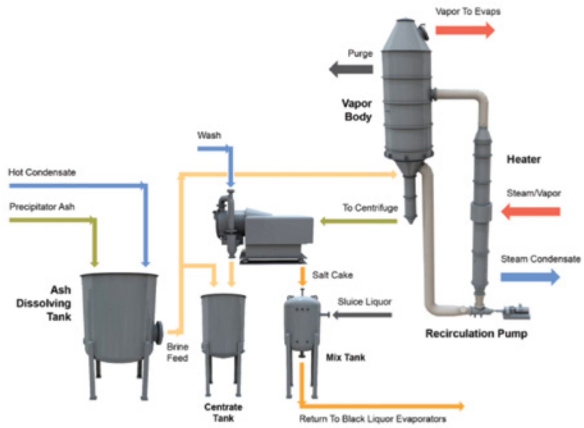

FIGURE 1. A typical chloride-removal process (CRP) in a pulping mill treats dissolved precipitator ash to remove contaminants and recover sodium salts

Pulping facilities require a great deal of water, chemicals and energy, which creates many challenges when it comes to sustainability. Although the modern pulping process includes sophisticated closed-loop processes with the ability to recover and reuse water, chemicals and energy, manufacturers should always keep a keen eye for additional opportunities that allow companies to lighten their environmental footprint. One of the key areas pulping facilities can target is to incorporate sustainability projects within the plant's ash-treatment recovery loop.

By enhancing the ash-treatment recovery process with capital improvements, companies can generate an advantageous proposition. In addition to improving overall plant efficiency, sophisticated ash-treatment projects can significantly reduce discharged waste materials and extend the lifespan of critical utility equipment, such as plant boilers — all top-of-mind issues for mill managers. On the sustainability side, enhanced chemical recovery within the ash treatment process has the potential to yield valuable byproducts, such as high-quality fertilizers.

Though these sustainability-focused projects may appear aggressive and require investments in new technologies or process changes, in many cases, they can significantly improve overall operational performance within the pulping process and achieve a quick payback on the capital investment. As a result, both greenfield and existing pulping facilities can harvest the benefits from implementing upgrades to their chemical-recovery and ash-treatment operations.

Chemical recovery and ash treatment

In most modern pulping mills, during the kraft pulping process, wood is cooked with water and chemicals at high temperatures in order to separate the cellulose from lignin and hemicelluloses. The resulting pulp is further washed with water. The water used to wash the pulp, plus the cooking liquor from the digester, is called "black liquor."

Black liquor is concentrated using evaporation in order to be combusted as a form of renewable energy within the recovery boiler. Combustion of the black liquor's solids leads to the generation of energy

and steam, which is used elsewhere within the plant. Contained in the molten salts (smelt) are most of the needed pulping chemicals, which are collected from the recovery boiler and can be reused in the digester.

This closed circulation loop maximizes the economics of chemical recovery, reducing chemical discharge and raw chemical makeup, but also creates challenges for handling and treating liquor streams. Nonprocess elements (NPEs), including chloride and potassium entering the mill through the raw wood and chemical makeup, accumulate in the recovery cycle. Over time, they create conditions for scaling and plugging in the boiler, leading to lower energy production. If left uncontrolled in the precipitator ash, NPEs can become a significant problem — causing corrosion and boiler fouling — ultimately resulting in a reduction in recovery boiler capacity and an increase in operating costs.

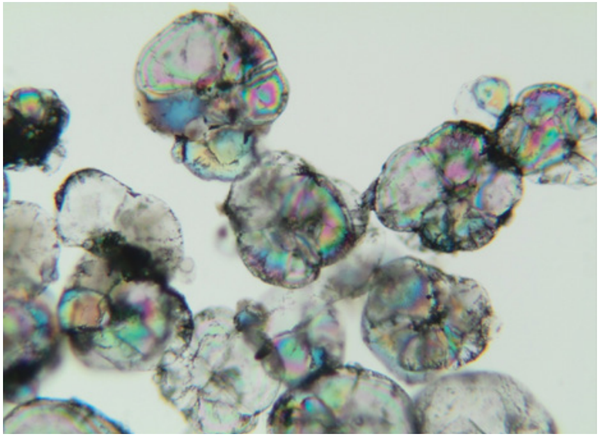

FIGURE 2. Glaserite crystals can form during the chloride-removal process when the crystallization chemistry exceeds solubility limits for potassium before reaching the chloride solubility limit

By integrating advanced chloride- and potassium-removal systems to treat the precipitator ash, mills can unlock significant operational benefits and reduced chemical costs, while simultaneously generating additional revenue streams from produced byproducts that also increase the sustainability of the production facility.

Chloride removal process

A two-stage crystallization process can be used for enhanced removal of NPEs. The first stage consists of a conventional chloride-removal process (CRP) system (Figure 1) operating close to atmospheric pressure, followed by a second-stage crystallization process designed to target potassium within the chemical recovery process.

Stage 1 — CRP. Precipitator ash is dissolved with condensate, resulting in a slightly under-saturated solution feed to the CRP system. The CRP system operates as a true crystallizer, with proper crystal generation, growth and washing to maximize the removal of contaminants and recovery of sodium salts. Crystallization occurs through evaporation of water, causing the solubility limit of sodium salts to be exceeded. The resulting sodium salt crystals are dewatered and washed in a centrifuge and returned to the recovery cycle via sluicing with black liquor. Chloride and potassium remain in solution and are purged from the crystallizer in a concentrated stream with minimal sodium losses. The CRP system is typically thermally integrated with a mill's black-liquor evaporation system in order to achieve low operational costs.

The conventional CRP system will achieve a maximum chloride-removal efficiency of 98–99% at a sodium recovery of 85–95%. For mills with higher potassium levels, the sodium recovery will be lower.

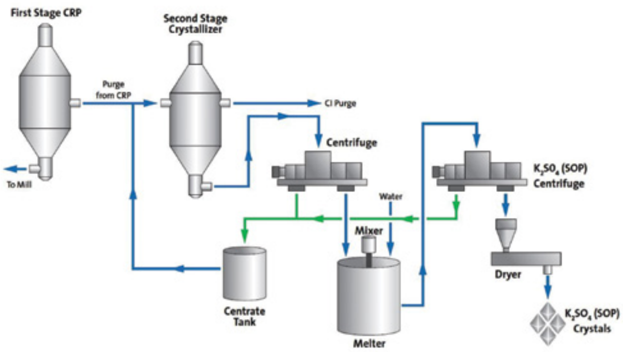

FIGURE 3. For mills with a particularly high concentration of potassium in the chemical-recovery unit, a second stage can be added to crystallize additional sodium salts and potentially produce a sulfate of potash (SOP) stream

CASE STUDY: BRAZIL PULPING MILL

A leading integrated producer, exporter and recycler of pulp and paper in Brazil was looking to expand its pulping operations.

Challenge

The Kraft process used in the production of pulp enables the efficient recovery of chemicals and heat in a closed-cycle process. However, it also allows the undesired buildup of chloride and potassium in the recovery cycle, which if left uncontrolled, can create corrosion and boiler fouling.

Solution

After analyzing the composition and performing small-scale pilot testing, it was confirmed that the installation of an enhanced chloride removal process (ECRP) as a second stage to the site's existing system would be able treat the additional feed of precipitator ash and prevent significant boiler-capacity losses and increased operating costs. With the new system, the site was able to treat up to 10 ton/h of precipitator ash (equivalent to 240 ton/d).

Creating value from byproducts

In this particular case, the SOP produced from the ECRP system was used by the mill to fertilize its forest reserves to enhance growth rates for the next generation of trees. In doing so, the facility was able to close the loop by returning high-quality nutrient compounds back into the environment. ❑

For the vast majority of pulp mills, the crystallization chemistry will exceed solubility limits for potassium before reaching the chloride solubility limit. In this case, a portion of the potassium present will crystallize as glaserite ($3K_2SO_4{\cdot}Na_2SO_4$), which is shown in Figure 2. The glaserite will be returned to the mill cycle with the other sodium salts, thereby reducing the CRP system's overall potassium-removal efficiency. As most pulp mills are more focused on chloride reduction, the CRP system typically will be operated in a way to maximize chloride removal and soda recovery, while the potassium removal generally ends up in the 70–90% range. Pulp mills with high potassium inputs may instead wish to maximize potassium removal and can be limited to 60–80% sodium recovery when optimal potassium removal is targeted. Most high potassium mills must balance potassium removal and sodium recovery in order to minimize the cost of sodium losses.

As a true crystallizer, the conventional CRP system is a highly selective purification process to maximize chloride removal efficiency and achieve high recovery of sodium salts. Mills that have a high level of potassium in their chemical recovery loop have a unique challenge and opportunity. By implementing a second stage to the CRP, mills can produce additional byproduct streams while simultaneously removing high levels of chloride and potassium.

Stage 2 — Potassium-handling enhancements. For mills with high levels of potassium in the chemical-recovery loop, a second stage can be added to complement the initial CRP stage (Figure 3). After the CRP stage, which is operating close to atmospheric pressure, sodium salts, such as sodium sulfate, burkeite ($2Na_2SO_4{\cdot}Na_2CO_3$) and sodium carbonate, are crystallized in the first stage and returned to the recovery cycle. The second-stage crystallizer acts as an adiabatic flash-crystallizer unit operating at lower temperature to take advantage of the reduced glaserite solubility. Crystallized glaserite solids are dewatered in a centrifuge for subsequent disposal or otherwise further processed for production of sulfate of potash (SOP; K_2SO_4) fertilizer. A portion of the glaserite crystallizer mother liquor is purged from the mill to further enhance overall chloride-removal efficiency, with the remainder of the mother liquor recycled to the first-stage CRP crystallizer.

Water added to the melter results in selective dissolution of the sodium sulfate and potassium sulfate from the glaserite, leaving purified potassium sulfate in the solid phase. The potassium sulfate may then be centrifuged and dried to produce a high-quality SOP byproduct.

Producing SOP

Crystallized SOP fertilizer (Figure 4) is a premium, water-soluble fertilizer that is uniquely positioned as a "smart fertilizer" that can allow for more consistent results and a higher quality crop yield. SOP's enhanced water solubility allows the fertilizer to be injected into advanced irrigation systems, which allows for a more efficient transfer of nutrients to plants. SOP fertilizers are also gaining traction over traditional fertilizers because of their extremely low levels of impurities like sodium, chlorine and heavy metals. These impurities not only can create issues by scaling and clogging within application equipment, but they can also cause adverse effects to crop quality, especially those sensitive to chlorides.

Because of these advantages, the demand for "smart fertilizers," such as SOP, is expected to significantly increase. This allows pulping facilities to be uniquely positioned as key contributors within the supply chain of SOP. With pulping facilities conveniently positioned across the globe, they can act as decentralized, local producers of this valuable resource. This has the potential to reduce supply-chain logistic costs and environmental impacts by shortening the distance between the source and user.

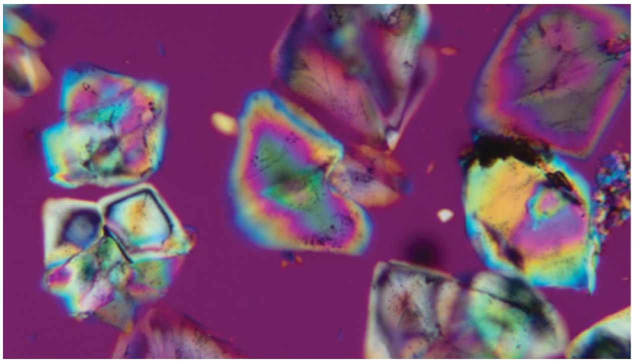

FIGURE 4. SOP is a high-value, crystallized fertilizer product that can create an additional revenue stream from pulping mills

Advanced chemical recovery technologies at pulping facilities can introduce significant benefits for companies, including reduced operating costs, reduced downtime, and of course the creation of high-value byproducts, such as SOP fertilizer, which can create additional revenue streams. With respect to sustainability, these enhancement projects generally result in reduced water usage, improved energy consumption, less waste, and in the case of sites that recover nutrients and produce SOP, these sites can also play a leading role in helping secure the global food chain, as well as support fertilization of carbon-capturing forests. ■

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Centrifugal Pumps: When to Repair, Replace or Modify?

When a pump operates inefficiently, or fails all together, the challenge is to make the most economical decision on how to remedy the situation. Some guidance is provided here

Robert X. Perez and Heinz P. Bloch
Consultants

IN BRIEF

- PUMP HYDRAULICS
- HYDRAULIC RERATES
- PUMP FAILURES
- REPAIR OR REPLACE?
- REPAIR/SPARE PART PHILOSOPHIES
- MAKING THE CASE FOR UPGRADES
- PAYBACK TIME EXAMPLES
- PUMP REPLACEMENT

Centrifugal pumps are widely used throughout the chemical process industries (CPI). Their reliable and efficient performance plays a significant role in plant operations. This article considers the different options on what to do when a pump begins to operate unreliably or fails.

Pump hydraulics

Operation far away from a pump's best efficiency point (BEP) is a common cause of pump unreliability. There are a number of reasons why a centrifugal pump may be found operating in an off-design condition: The pump may either have originally been misapplied or the process requirements may have changed since its initial specification and installation. Two minimum flows must be satisfied on the pump curve for reliable service: 1) The minimum continuous stable flow (MCSF), which prevents internal recirculation; and 2) the minimum thermal flow, the point where rapid internal heating begins. The pump manufacturer will usually state the MCSF for its pumps in its documentation. For best overall performance, it is always best to keep the operating point above the hydraulic minimum flow.

Regardless of the reason for pump misapplication, the effects of a poor hydraulic fit will typically be dismal reliability performance and poor overall system efficiency. Figure 1 shows the numerous adverse effects of operating too far away from a pump's BEP "sweet spot." In the field, problems related to off-design operations are typically manifested by higher than normal vibration levels and frequent bearing and seal failures.

Hydraulic rerates

One solution available to avoid problems caused by an oversized centrifugal pump is to perform a hydraulic rerate on the pump's fluid end. The basic idea of a pump hydraulic rerate is to fit an impeller with a lower flow rating inside the existing oversized pump casing. To accommodate a new impeller, case-wear-ring adapters are used to allow

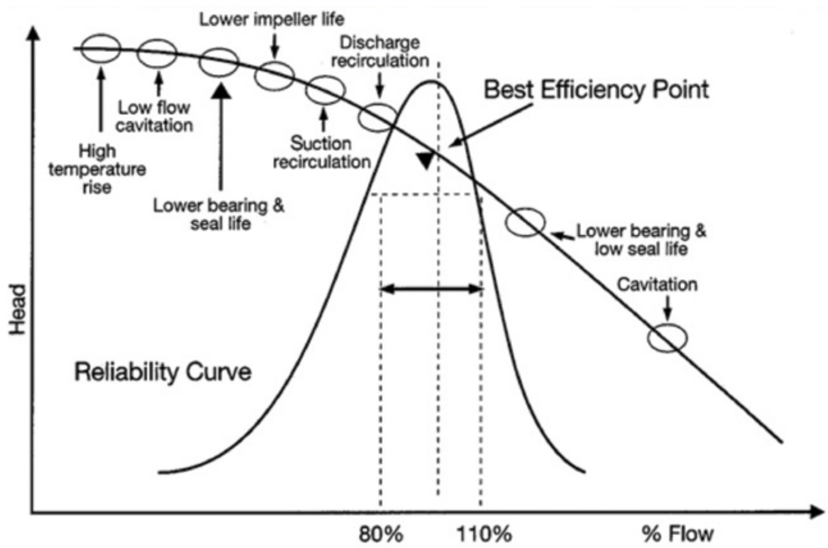

FIGURE 1. The Barringer-Nelson curve shows reliability impact of pump operation away from BEP (Source: Paul Barringer)

for smaller diameter sets of casing and impeller wear rings. This would also be a fine opportunity to consider advanced perfluoralkyl (Vespel CR-6100) stationary wear parts.

In addition to these modifications, volute throat area(s) must be matched to the new impeller. This is done by cutting out the original volute lips and welding in custom-designed volute lips. This simple, straightforward design approach can provide pump users a cost-effective solution to chronic failures caused by hydraulic instabilities.

Performing a hydraulic rerate is the task of mechanical engineers, and outside the scope of this article. More information on how to do this and the benefits can be found in Ref. 1. We now focus on the decision-making process for handling a pump failure.

Pump failures

When a centrifugal pump fails, there are several possible paths forward that a processing facility may consider. The following options are possible:

- Repair the existing pump (Figure 2) at an outside shop or in-house using replacement parts from stores
- Replace it with a rebuilt pump (in kind) kept in stores
- Replace it with an identical pump kept in stores or purchased from a distributor or manufacturer
- Repair it with key upgraded mechanical component(s) to improve mechanical reliability
- Perform a hydraulic rerate using the existing pump casing to improve the hydraulic fit (as briefly described above)
- Replace existing pump with a completely different model pump that better fits the service

It is important that all centrifugal-pump maintenance decisions be economically justified, meaning that the benefits derived from the repair, replacement or modification must be of greater value than the base cost. For maintenance events, such as repairs, the value added by the repair should exceed the cost of the repair. For major modifications, economic criteria, such as the investor rate of return (IRR) and net present value, should be used to objectively evaluate the benefits of the initial investment. The benefits of modifications and replacements are typically increased reliability, an improvement in efficiency, or both. A faithful economic justification requires that the user understands all the benefits derived by the modification along with all the associated modification costs.

To decide which path forward makes the most economic sense, the reliability professional first needs to know the following:

1. What is the length of time since the last repair or the current mean time between failures (MTBF) metric? Best-of-class pumps easily reach MTBF between six to ten years. Pumps with MTBF of less than two years should be considered completely unacceptable. Therefore, pumps providing MTBF performance

greater than six years should continue to be repaired as usual and pumps providing MTBF performance less than two years should be scrutinized for improvement opportunities. Pumps with MTBF between two and six years should be reviewed on a case-by-case basis.

2. What is (are) the root cause(s) of the most recent failure? The pump owners must understand why their pump is failing before an upgrade or replacement pump can be evaluated. The most effective modifications are those that address the root cause of past failures.

3. How is the pump performing and how close to BEP is it operating?

4. What is the cost to restore the pump back to the manufacturer's specifications?

5. What is the value of process downtime related to an unplanned pump failure?

6. What is the cost of an in-kind replacement pump and its delivery time.

7. What is the cost to keep a replacement pump in stores?

8. What is the cost of design improvements being considered?

9. What is the total cost of a centrifugal pump hydraulic rerate being considered?

10. What is the total cost to replace an existing pump with one that has a better hydraulic fit?

Repair or replace?

A common question that comes up when pumps fail: Which pump warrants repair and which should simply be replaced? As described in Ref. 1, the economic test for deciding if a pump should be repaired or replaced can be stated as follows: If the value added by the repair is greater than the repair cost minus its salvage value, then it makes more sense to repair the pump than replace it. This can be expressed by Equation (1):

$$m_{pr} - m_s = r_{va} \geq r_c \qquad (1)$$

Where:
m_s = market salvage value
m_{pr} = market value of the pump after repair
r_{va} = value added to the pump by the repair
r_c= repair cost

From this relationship, we can conclude that only repairs that produce an added value greater than the cost of repair makes economic sense. This statement assumes that the pump in question can be removed from service and repaired without an economic penalty.

Here are a few examples illustrating how the value-added relationship works:

Example 1. Consider repairing a 150-hp centrifugal pump with the following costs:
Pump salvage value = \$2,000
Post repair pump value= \$20,000
Value added = \$20,000 – \$2,000 = \$18,000
Repair cost = \$8,000

Plugging these values into Equation (1), we see that \$18,000 > \$8,000. Therefore, a repair is justified in this case since the value added by the repair is greater than the repair cost.

FIGURE 2. A mechanic inspects a centrifugal pump impeller during a repair

Example 2. Consider repairing a 5-hp centrifugal pump with the following costs:
Pump salvage value = \$500
Post repair pump value = \$2,000
Value added = \$2,000 – \$500 = \$1,500
Repair cost = \$4,000

Plugging these values into Equation (1) we see that \$1,500 < \$4,000. In this case, a repair is not justified since the value added by the repair is less than the repair cost.

The reader will note that the lower the replacement cost, the more likely it will make sense to replace a pump than to repair it. Some facilities set a horsepower limit to define when failed pumps are simply replaced, which simplifies the decision-making process for a repair shop.

Repair/spare part philosophies

Once a pump is installed, site management decides its criticality and if it makes sense to repair it or replace it when it fails. Pumps that are fully spared are considered less critical, while pumps that are unspared (non-spared) are considered more critical. There are several cases to consider, as follows:

- For smaller, less critical pumps (<5 hp), which are uneconomical to repair, either keep complete pump replacements in stores or order replacement pumps from the manufacturer or distributor when required. The decision to either stock a complete spare pump or order it when required will depend on the expected delivery time.
- For a fully spared pump that can be removed and repaired because the other installed spare is deemed to be reliable and capable of supplying the required flow on its own: In services with medium- to large-size pumps, it makes sense to pull the failed pump and repair it — either in the shop or off site.
- For a fully spared pump that can be removed without impacting the process but takes too long to repair: This might apply to troublesome pumps that fail frequently, which may mean that time to repair may approach or exceed the time between failures. In these services, it makes sense to keep a rebuilt or new pump in stores. When needed, the replacement pump can be removed from the warehouse and installed in the field.
- For when an unspared pump's downtime must be minimized due

TABLE 1. LIKELIHOOD PROJECT WILL BE APPROVED, BASED ON THE PAYBACK PERIOD	
Payback Period Range	**Comment**
< 1 year	Sure to be approved
>1 year but <2 years	Likely to be approved
>2 years but <5 years	Difficult project to sell
>5 years	Not likely to be approved

to its potential economic impact on the plant: These pumps tend to be more complex and costly, so it makes sense to store a pump bundle or rotating assembly in the warehouse to minimize the repair time in the event of major failures. Spare seals, bearings and couplings should also be kept in stores for minor repairs.

An ineffective spare-parts management program can negatively affect pump reliability at your site. For this reason, spare parts management should be an integral part of every pump reliability program. However, often spare parts management tends to fly below the radar and is often given little thought or consideration. To maintain the effectiveness of the program, a team consisting of a rotating equipment engineer (or professional), shop foreman, warehouse specialist and a management representative should be involved in all critical spare part decisions and tracking. The team should also meet regularly to discuss: 1) the status of all critical spares; 2) current spare-part stocking levels; 3) changes in stocking levels; 4) decisions to dispose of obsolete inventory; 5) addition or deletions of suppliers; 6) stocking upgraded parts, if available, and so on. After some trial and error, an optimal mix of spare parts will be determined for your given centrifugal pump population.

Making the case for upgrades

Rotating machinery professionals are always looking for ways to improve the reliability or capabilities of their process pumps. However, there is always a limit to the level of improvements that are economically justified. The economical limit is governed by the law of diminishing returns [2], which is an economic law stating that if one input in the production of a commodity is increased, while all other inputs are held fixed, a point will eventually be reached at which additions of the input yield progressively smaller, or diminishing, increases in output.

In centrifugal pump applications, the pump's reliability or process capability are usually considered the commodity of interest, while various design improvement options can be considered inputs to improve reliability or capability to a given economic evaluation. There is a limit to how many economical improvements can be made to any given machine. Eventually, the n^{th} improvement will no longer be economically justified. Here are some examples of common centrifugal pump improvements:

- Upgrading mechanical seals and related sealing systems in a pump to improve reliability
- Upgrading pump casing metallurgy to increase useful life
- Installing vibration monitoring equipment to prevent catastrophic failures
- Rerating a pump to allow operation closer to its best efficiency point (BEP) flow to improve hydraulic stability
- Installing a spillback line in a pump's discharge line to prevent operation below its minimum continuous stable flow (MCSF) to prevent internal recirculation at low-flow demand conditions

The payback-period method explained here is a simple means of evaluating the benefits of a potential upgrade to management. The payback period is defined as the initial investment divided by the expected annual revenue realized by the improvement. The payback period of a modification is determined by dividing the total installation cost of the upgrade by the annualized benefits:

$$Payback\ period = \frac{Installation\ cost}{Annualized\ benefits} \quad (2)$$

Installation costs can include, but is not limited to, the following items:

- Cost of new components and equipment
- Demolition and installation costs
- Warehouse spares
- Required training and modification/updating of operating procedures

The annualized benefits may include the following:

- Reduction in repair costs
- Reduction in production losses
- Increase in process throughput
- Energy savings

Note that annualized benefits are relative terms. To define an economic benefit, you need to have a future case and a base case. For example, if a pump is failing twice a year and costs $10,000 per repair, then the base maintenance cost is $20,000/yr. If you expect the pump failure-rate interval to increase to once every 5 years, then the future maintenance costs are expected to be $10,000/5 or $2,000/yr. In this example, the annualized benefits of the upgrade are expected to be $18,0000 per year. The point here is you must always consider the future case and the base case in determining the annualized benefits,

$$Payback\ period = \frac{Total\ cost}{\Delta Risk} = \frac{Total\ cost}{(Base\ case\ risk - Future\ risk)} \quad (3)$$

The annualized risk, or simply risk, is defined here as the sum of all the annualized losses associated with the failure mode being analyzed. Therefore, the annualized risk is equal to the annualized maintenance costs plus the annualized process losses plus the annualized environmental fines plus the annualized demurrage costs and so on. When evaluating the economics of reliability projects, we need to know the differential between the base risk and the future risk expected from the improvement. This differential is defined as the △Risk, which is the annualized benefit, or revenue, expected to be realized from a reliability improvement project.

For example, assuming a pump failure results in a $20,000 repair, a $50,000 process loss, and a $100,000 demurrage cost, then the losses experienced per seal failure is $170,000. If the pump is failing twice

TABLE 2. PUMP REPLACEMENT ECONOMICS	
Year	**Revenue**
0	($500,000)*
1	$64,990
2	$66,940
3	$68,948
4	$71,016
5	$73,147
6	$75,341
7	$77,601
8	$79,930
9	$82,327
10	$84,797
11	$87,341
12	$89,961
13	$92,660
14	$95,440
15	$98,303
16	$101,252
17	$104,290
18	$107,419
19	$110,641
20	$113,960
IRR	14.41%
NPV	$617,276.87
Rate	4%

*Note: Investment

a year, then the annualized base case risk is 2 × \$170,000 or \$340,000/yr. If we believe an upgraded pump will only fail every five years, then the annualized future risk is expected to be 0.2 × \$170,000 or \$34,000/yr. Therefore, the annualized $\triangle$Risk for this project is \$340,000/yr minus 34,000/yr or \$306,000/yr.

Table 1 tabulates some improvement-project payback-period ranges along with the likelihood projects that fall in these ranges will be approved by management (based on the authors' experiences).

Payback time examples

Two examples of determining the payback time are presented here.

Upgrading mechanical seals in a pipeline pump. Assume there is a multistage (double-ended), pipeline pump that is experiencing a seal failure every six months. Experience has shown that if only the leaking seal is replaced, then the non-leaking seal will normally fail within a few days. For this reason, it is considered good practice to replace both seals when either one of the seals has failed.

Root-cause failure analyses (RCFAs) in the pump's historical record indicate that most of the seal failures are due to abrasives embedding in the softer primary ring and causing a leak. After considering several options, it has been deemed that installing double seals with a dedicated pressurized-seal oil system is the most attractive of the upgrade options considered. It is believed that a pressurized sealing arrangement will increase the mean time between seal failures from 6 months to 8 years. If the cost of replacing inboard and outboard seals is \$40,000, then the annualized reduction in maintenance costs realized from the upgrade is expected to be:

$$\begin{aligned} &\$40{,}000/(0.5\text{ yr}) – \$40{,}000/8 \\ &= \$80{,}000 – \$5{,}000 \\ &= \$75{,}000/\text{yr} \end{aligned}$$

The upgrade costs include purchasing four seals (two to install and two to put in stores), a pressurized-seal oil system, and the cost of installing the required seal auxiliary piping and instrumentation for the new seal oil system. No modifications to the pump shaft or pump casing are required for the seal upgrade. The total project cost of the upgrade is estimated to be \$120,000.

Using Equation (3), we see that the payback period for this project is \$120,000/\$75,000 = 1.6 yr. Referring to Table 1, we can see that this project has a good chance of getting approved. (Notice that this simple economic analysis did not take credit for any pipeline outages or slowdowns caused by unplanned seal replacements. Taking credit for any process related losses will decrease further improve the payout period and make this upgrade project even more economically attractive.)

Upgrading slurry-service pump casings. Let's say you own a pair of 500-hp slurry pumps that, due to severe casing erosion, are currently experiencing one failure every year. Every time the failure occurs, it costs \$100,000/yr to pull the pump, replace with casing with a spare casing in stores, and expedite the reassembly and installation. An RCFA indicates that the current metallurgy and coating combination is unsuited for the application.

Assuming we believe you can improve the MTBF of these pumps from once every year to once every four years, then the annualized benefit of a casing upgrade will be \$100,000/yr – \$25,000/yr = \$75,000/yr. If the cost of the new upgraded casing is \$60,000, then the total project cost will be \$180,000 (for the main, installed spare, and warehouse spare). We won't include the cost of installing the new casings, since future repairs have already been accounted for.

Using Equation (3), we find that the payback period for this example will be \$180,000/\$75,000/yr = 2.4 yr. According to Table 1, a project with a payback greater than two years may be difficult to sell to site management. To increase the chances of getting this upgrade approved, the user may have to find additional upgrade benefits, such as listing any production downtime events caused by unexpected failures or taking a salvage credit for the existing casings.

Remember that the payback period evaluation method does not consider the time value of money as considered in other economic analysis methods. However, most managers tend to find the payback method to be an intuitive and acceptable means of evaluating the economic benefits of smaller projects. Other larger or more complex projects may require more sophisticated economic evaluations, such as determining the internal rate of return (IRR) or net present value over the life of a project.

Some final advice on upgrades: To be successful, centrifugal pump professionals should 1) use economic thinking when considering all potential upgrade decisions; and 2) always try to justify your projects using clear, well thought out project scopes that have compelling payback time calculations. Never push improvement

projects that are not justified and always listen to your managers' concerns if they question your calculations or assumptions. Don't let your enthusiasm get in the way of your company's best interests.

Pump replacement

Typically, the costliest way to improve a pump's reliability performance is by completely replacing it with one that is better suited for the application. Initially, site personnel tend to seek improvement with mechanical seal, metallurgy, bearing upgrades or modifications to operating procedures in their attempts to gain better reliability. Yet, after years of frustration, site management may eventually have to concede that the existing pump or pumps were completely misapplied.

When considering a centrifugal pump replacement, the project group must first find a pump that fits the current hydraulic requirements. If several pump designs are being considered, the pump that requires the least piping modifications is usually favored above the other options. If the selected pump will not fit on the existing foundation, then the cost of the new foundation, or modifying/adapting foundations and/or base plates must be included in the total project cost. Other miscellaneous project costs, such as replacing warehouse spares, training of maintenance and operations personnel, required control modifications, and so on, must also be included in the total cost of the project.

As an example, consider having two 150-hp pumps that are oversized and operate at 25% of the BEP flow. The repair history shows that the pumps have been repaired, on average, once yearly at a cost of \$20,000 per repair for the past five years. A review of the pump curve shows that the current hydraulic efficiency is about 27%. The most attractive replacement pump option being considered can provide an efficiency of 67%. The energy savings from the more efficient pump have been calculated to be \$46,990/yr (based on an energy cost of \$0.097/hp-h). We will assume that a new, more reliable pump pair will, on average, have a MTBF of 10 years, which equates to a maintenance cost savings of \$20,000 – \$20,000/10 or \$18,000/yr. These findings mean that the project will attain a total annual revenue stream of \$46,990/yr plus \$18,000/yr (or \$64,990/yr). (Note that this total does not include any process losses or additional operational labor costs.)

After researching pump and piping options, the project group has determined that replacing these pumps will cost \$500,000, which includes the cost of two new pumps (assuming there is a main and an installed spare) all design costs, recommended spare parts, and all field modifications and installation costs. If we enter these data into an Excel spreadsheet and solve for the internal rate of return and the net present value (NPV), we get the output data shown in Table 2. There we can see that the IRR (14.41%) and NPV (\$617,276) for this project are factorable, which is the first hurdle the project will face.

Next, management will compare these economic projections with the other competing projects being considered at the time. Since capital budgets are finite, only the most attractive projects will be funded. The possible outcomes are that the project will either be fully funded, deferred until the next capital budget review, or canceled. Reliability professionals must realize that many reliability-improvement projects never see the light of day for reasons outside of their control. At the end of the day, remember that only well-conceived reliability improvement projects are ever fully approved and eventually realized. To have a realistic chance of approval, reliability projects need to have excellent economics numbers and key sponsors who will support the project every step of the way. Sponsors can be reliability managers, operations superintendents, plant managers, and executives. ■

Edited by Gerald Ondrey

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An Overview of Synthetic Filter Media

Many factors impact the performance of synthetic filtration media, from thread and weave styles to drainage and coverage considerations

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Under the broad umbrella of filter media, there are many synthetic media materials, including woven filter cloths, woven and non-woven fabric filter media and filter felts. The term "synthetic" encompasses cloth materials made of polyethylene (PE), polypropylene (PP), polyester or nylon, as well as other specialty materials, such as Saran, polyamide, Nomex (flame-resistant meta-aramid), polyether ether ketone (PEEK), fluoroplastics and other specially made materials for specific applications. A sub-category of such media includes wire-cloth filter media. These are woven wire mesh made of a variety of metals, the most common being wire mesh made of stainless steels, such as 316 SS and 316-L SS.

Originally, the materials used for filter media were silk, cotton and wool. Due to the limitations on the usability of those materials, synthetic materials are used much more often in industrial filtration applications since their introduction around 1945. Since then, rapid development activities have widely expanded synthetic fibers' applicability in industrial filtration. While cotton and wool are still used as filter media, this article covers synthetic filter media and wire cloth only.

Common fiber types

As shown in Figure 1, there are several common types of fibers used in synthetic filter media, as follows:

- Staple fiber fabrics — Yarns made of many short fibers
- Spun filament fibers — Yarn made from multiple discontinuous, small monofilaments twisted together
- Monofilament fabrics — Fibers produced from single extruded yarns
- Multifilament fabrics — Fabric made from yarns that have several continuous monofilament strands bundled together
- Woven wire fabrics — Media produced using metallic wires

Also note that combination materials are available, such as mono/multifilament, mono/staple and multi/staple combinations.

Monofilament fibers offer many benefits, including excellent diameter control for precise fabric openings, high flowrates, low pressure drops, relatively high stiffness and tensile strength. With these fibers, the filtration mechanism is surface particle capture, exhibiting excellent surface particle release. This media is easy to clean, and also demonstrates limited liquid absorption.

With multifilament fibers, users should note that the twisted yarns can often result in uneven yarn diameters, and pore sizes can be uneven and difficult to measure. With this type of media, the filtration mechanisms include particle

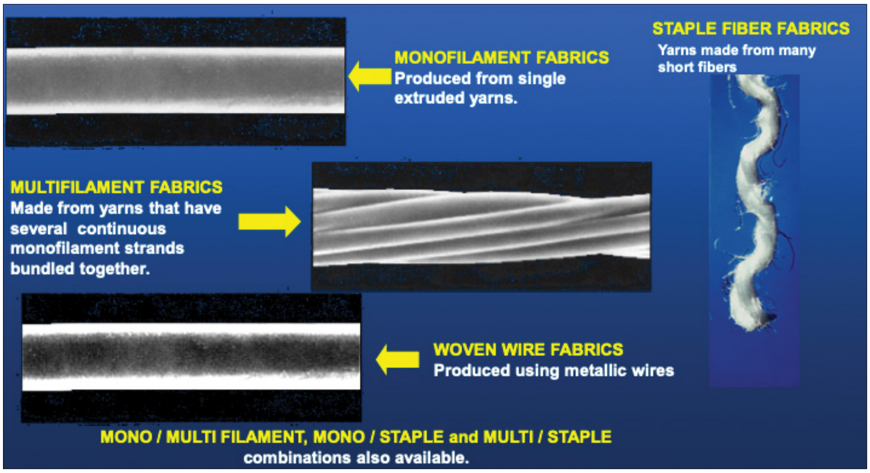

FIGURE 1. The fiber type used for filtration media can impact its final performance

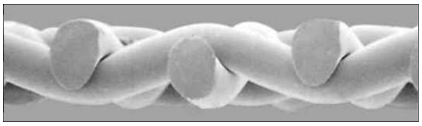

FIGURE 2. Square weave is the most basic weave style used with synthetic materials and wire cloths

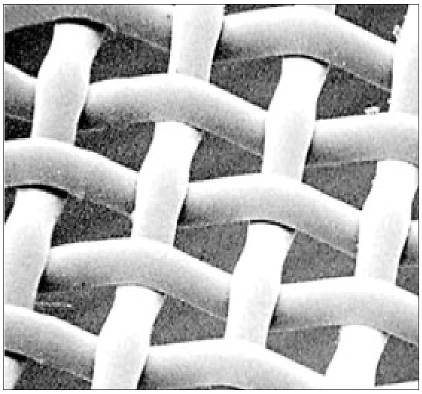

FIGURE 3. Square weaves imbue media with high permeability and stability

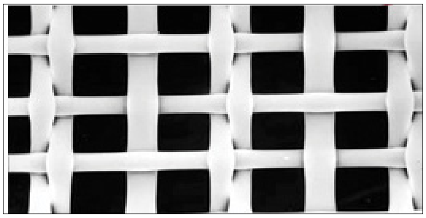

FIGURE 4. A taffeta weave gives media a rougher surface that mimics silk cloths

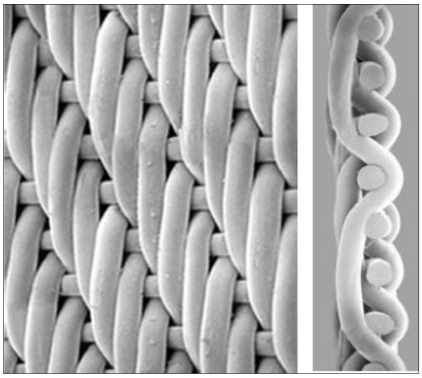

FIGURE 5. Closed twill weaves are denser, and result in strong and durable media

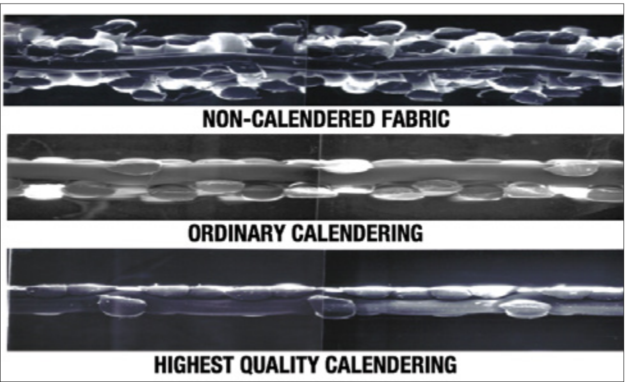

FIGURE 6. In calendering, controlled heat and pressure are applied to a material, yielding a more compact, denser fiber

capture on the surface, as well as between twisted strands. Multifilament media elements exhibit fair surface particle release, but they are somewhat difficult to clean. Their benefits include excellent tensile strength, flexibility, pliability and fatigue resistance. It also should be noted that multifilament yarns can absorb liquids.

Spun filament fibers are characterized by a somewhat uneven fiber size and density, and like multifilament fibers, their pore sizes can be uneven and difficult to measure. The filtration mechanisms for spun filament fibrous media include particle capture on surface, as well as within the fiber structure. While these media are indeed flexible and pliable, they exhibit poor surface particle release, and are difficult to clean. As with multifilament fibers, spun filament yarns can absorb liquids.

Common weave styles

The method used to weave fibers into the larger filter-media elements can make a significant difference in performance parameters. Several weave styles are described in the following sections. The pore sizes available for the main weave categories are given in Table 1.

Square weaves. This weave style is mainly used with synthetic materials and wire cloth. It is the most basic open-weave style, employing a simple over-and-under pattern (Figures 2 and 3). It provides a straight flow path with a large open area. Some of the main benefits of square weaves are: high permeability, minimal binding, easy cleaning and high stability.

TABLE 1. PORE SIZE OPTIONS FOR WOVEN FILTER CLOTH MEDIA

Synthetic materials
Plain square weaves — down to 5 µm Closed Dutch and twill — down to 10 µm
Wire cloth
Plain square weaves — down to 20 µm Closed Dutch weaves — down to 1 µm

Taffeta weave. This weave style is typically used with synthetic materials only. It is a variation of square weaves where two small-diameter threads alternate with larger-diameter threads in the warp direction (Figure 4). "Warp" refers to the wires running the length of the cloth as it is woven. This style, with its rougher surface, mimics silk molting cloths.

Closed twill weave. This weave style is used with synthetic materials. The denser weave pattern involves the warp threads going over three times, then under one weft thread (Figure 5). This weave style promotes excellent strength and durability. Filter media employing this weave style may be calendered to control air permeability. Calendering is a fiber treatment process whereby pressure and heat are applied at the same time to compress the fibers together, resulting in a thinner and tighter fabric with better filtration quality. As seen in Figure 6, calendering results in a more compact, denser fiber.

Twill Dutch weave. This weave style is used with wire cloth media. It provides the finest particle retention with its two-over, two-under pattern. In this style, the warp wires are heavier than the shute wires (the wires running across the width of the cloth).

Plain reverse Dutch weave. This weave style is used with both synthetics and wire cloth media. It has a higher warp thread count versus weft threads (Figure 7). The warp yarn diameter is generally two-thirds of the weft yarn diameter. This weave style can accommodate high flowrates, and it provides excellent longitudinal flexibility, transversal rigidity and tortuous flow.

Plain Dutch weave. This weave style is used with wire cloth media in high-flowrate applications. Its shute wires are smaller than its warp wires (Figure 8). A benefit of this weave style is a low pressure drop across the media.

Double-layer weaves. Double-layer weaves are used with synthetic media. These can be of the monofilament or mono-multi-weave variety. In double-layer weaves, the filter layer (for example, a closed twill-weave filter) and the support layer (for example, an open-square weave) are woven together. This configuration results in fine filtration capabilities, as well as exceptional strength and durability. There are various constructions available for double-layer woven media (Figure 9). Since fine fabric is woven onto a strong support layer, fabric pores tend to "blind-off" against a perforated metal support, as seen in Figure 10. In a monofilament configuration, lateral flow through the coarse mesh bottom layer results in improved flow and throughput (Figure 11).

Performance considerations

When selecting the proper filter media, the main performance issues taken into consideration are particle capture efficiency, throughput capacity, washability, cake release, temperature resistance and chemical resistance. Table 2 provides information on temperature and chemical resistance for several common synthetic materials.

Particle capture efficiency. It is important to note that 100% particle capture efficiency is often not necessary, as it may be too costly to be feasible in a particular project. Furthermore, fabric pore size does not necessarily have to exactly match

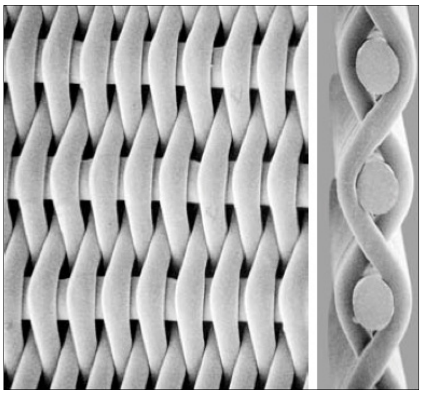

FIGURE 7. Filtration media employing plain reverse Dutch weaves can handle high flowrates

TABLE 2. FILTER CLOTH CHARACTERISTICS

Fiber	Acid resistance	Alkali resistance	Recom-mended temperature limit, °F	Flex and abra-sion	Wet filtration characteristics
Cotton	Poor	Fair	210	Fair	Offers good particle retention; is unaffected by dilute acids, but is susceptible to hot, weak acids or cold, concentrated acids; poor resistance to mildew and fungi
Nylon	Fair	Excellent	275	Excellent	Very good abrasion resistance; high tensile strength and elasticity; unaffected by mildew and fungi; degraded by oxidizing agents and mineral acids, but resists most common alkalis
Polyester	Very good	Good	300	Very good	Highly tolerant of oxidizing agents; good resistance to acids, except for concentrated nitric and sulfuric acids; Highly resistant to solvents; Degrades under hydrolysis
Acrylic homopolymer	Excellent	Fair	285	Good	Very resistant to mineral acids; medium resistance to weak alkalis and strong alkalis at room temperature; not harmed by common solvents
Polypropylene	Excellent	Excellent	200	Very good	Lower density than all other synthetic fibers; resistance to alkalis and acids, as well as many solvents, except aromatic and chlorinated hydrocarbons
Polyethylene	Excellent	Excellent	180	Good	At room temperature, can withstand alkalis, acids and many organic chemicals; features good elasticity and recovery
Saran	Excellent	Excellent	180	Good	Can resist mineral acids, most alkalis, chlorine and alcohols; is very durable in the presence of acids, particularly HCl and alkalis, except ammonium chloride
Nomex	Fair	Excellent	425	Very good	Very similar to nylon, but can withstand higher temperatures
Glass	Excellent	Fair	600	Poor	Highly resistant to acids, except hydrofluoric acid and hot phosphoric acid in their concentrated forms; vulnerable to abrasion and flexing

the capture objective (as in cake filtration, for instance).

Throughput capacity. When considering throughput capacity, it should be understood that media with the same pore sizes can exhibit different throughputs, as shown in Figure 12. The open area of the media is what will ultimately set the capacity.

Washability and cake release. These considerations describe how well the cloth can be washed, and how well the filter cake releases when cleaning the filter cloth. Both of these factors help to predict the lifecycle effectiveness of the media.

Drainage

Consideration must also be given to providing a drainage support between the filter media and the surface underneath. In the case of filter cloth media, it has been found in some cases that providing a drainage support consisting of a coarse, open media types may increase flow by as much as 20%. The drainage support is either an open-square weave made with coarse threads or filaments, or what is known as honeycomb. The drainage member separates the cloth from the metal support and thus creates more flow, since it allows for a lateral flow under the

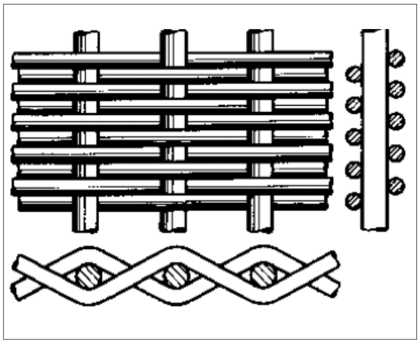

FIGURE 8. The plain Dutch weave style enables a very low pressure drop across the media

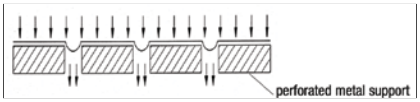

FIGURE 10. In double-layer weaves, fine fabric is often woven onto a perforated metal support

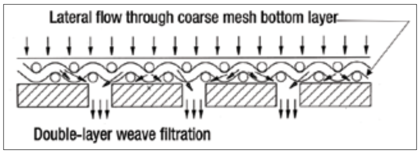

FIGURE 11. In monofilament double-layer weaves, improved throughput is achievable due to lateral flow across the coarse, mesh bottom layer

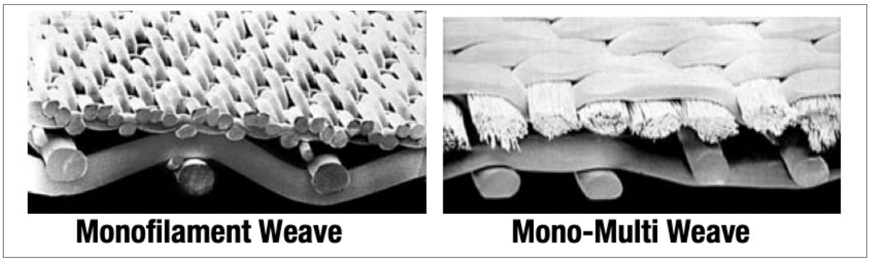

FIGURE 9. Double-layer weaves can be configured as monofilament or mono-multi weaves. Both options involve a filter layer that is woven together with a support layer

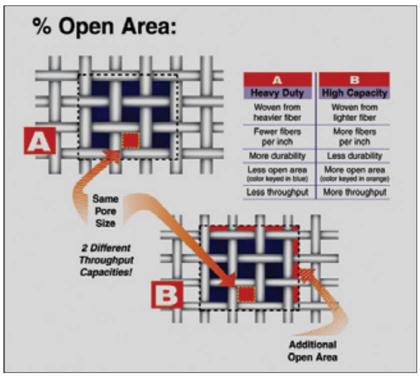

FIGURE 12. Throughput capacity is not dictated by pore size, but rather the open area of the media

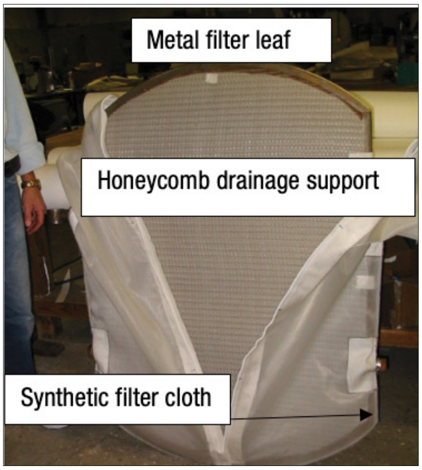

FIGURE 13. This metal filter leaf is equipped with a honeycomb-style drainage support, which helps to increase flow through the filtration elements

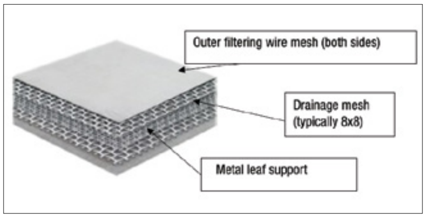

FIGURE 14. Drainage mesh on filter leaves can help separate the cloth from the metal support

cloth. In the case of the woven wire mesh, the drainage member is usually a more open coarse-square mesh, such as 8 × 8 mesh. Figure 13 shows a metal filter leaf with the honeycomb support and the synthetic cloth cover open to show the support. Figure 14 shows a five-ply filter-leaf construction with drainage mesh.

Filter-cloth covers

While filter-cloth covers are sewn when originally installed onto the filter leaves, replacement filter-cloth covers may be supplied with either Velcro closures or zippers to facilitate field installation and eliminate the need to be sewn, which may require sending the filter leaves to a shop for sewing. Care must always be taken to prevent dragging filter leaves with cloth covers on them across the floor. This will tear or rip the cloth. Also, users must be careful not to hit the covered leaves against sharp surfaces that might damage the cloths. The cloths should be inspected periodically for any wear, tears or holes in the cloths. Such damage will most certainly affect the filter's performance. A good preventative measure is to supply the cloth covers with reinforcement patches either on the corners, or any areas where the bags may be subject to friction or wear. ■

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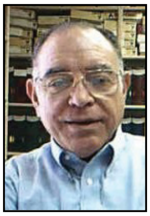

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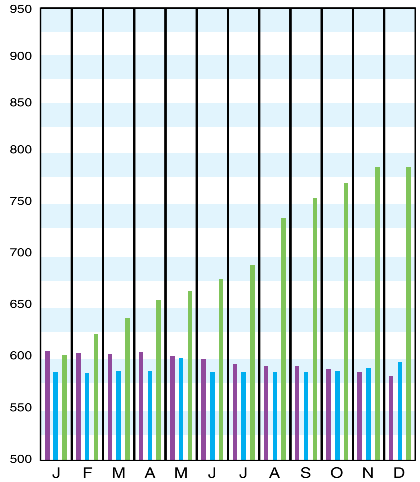
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Dec. '21 Prelim.	Nov. '21 Final	Dec. '20 Final
CE Index	776.9	773.1	606.9
Equipment	979.7	973.8	737.3
Heat exchangers & tanks	832.6	825.7	621.4
Process machinery	977.6	976.7	737.7
Pipe, valves & fittings	1415.0	1402.1	998.7
Process instruments	564.0	569.3	433.4
Pumps & compressors	1179.4	1178.8	1086.2
Electrical equipment	679.0	672.4	571.2
Structural supports & misc.	1064.9	1056.6	772.5
Construction labor	348.0	348.2	336.4
Buildings	808.1	796.3	621.0
Engineering & supervision	303.3	310.5	311.6

Annual Index:
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2

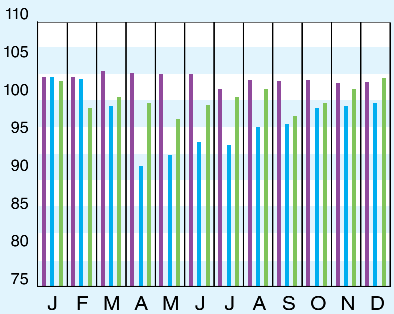


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

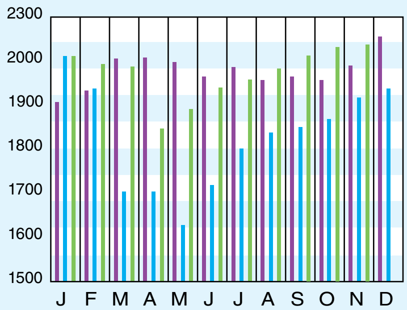
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2017 = 100)	Dec. '21 = 99.8	Nov. '21 = 99.9	Oct. '21 = 98.9	Dec. '20 = 95.0
CPI value of output, $ billions	Nov. '21 = 2,108.1	Oct. '21 = 2,090.2	Sept. '21 = 2,020.8	Nov. '20 = 1,711.2
CPI operating rate, %	Dec. '21 = 79.5	Nov. '21 = 79.7	Oct. '21 = 78.9	Dec. '20 = 75.6
Producer prices, industrial chemicals (1982 = 100)	Dec. '21 = 340.0	Nov. '21 = 340.5	Oct. '21 = 332.8	Dec. '20 = 240.0
Industrial Production in Manufacturing (2017 =100)*	Dec. '21 = 100.2	Nov. '21 = 100.5	Oct. '21 = 99.9	Dec. '20 = 96.8
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '21 = 195.8	Nov. '21 = 194.6	Oct. '21 = 195.1	Dec. '20 = 194.3
Productivity index, chemicals & allied products (1992 = 100)	Dec. '21 = 96.4	Nov. '21 = 96.7	Oct. '21 = 358.0	Dec. '20 = 92.1

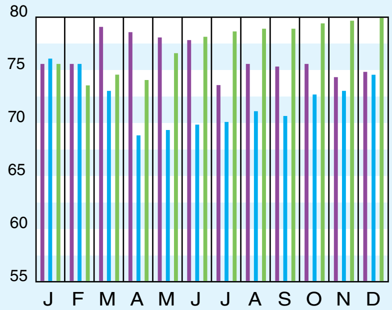
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for December 2021 (most recent available) rose compared to the previous month, extending the increases observed throughout 2021. For December 2021, increases in the Equipment and Buildings subindices more than offset reductions in the Construction Labor and Engineering & Supervision subindices. The current CEPCI value now sits at 28.0% higher than the corresponding value from December 2020. Meanwhile, the Current Business Indicators (middle) showed slight decreases in the CPI output index and CPI operating rate for December 2021, and a small increase in the CPI value of output for November 2021.